

Postglacial Variations in Aquatic Productivity in
Found Lake, Ontario

by

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ABSTRACT

Found Lake terrestrial vegetation changes were correlated with estimates of the availability of nutrients especially of phosphorus during the lake's history. It was proposed that nutrient availability was regulated by a complex interaction of factors relating to vegetation type, soil and water conditions, climate, and erosion. The greater biomass and nutrient content of deciduous litter along with the favourability of the environment for enhanced organic matter decomposition were considered to be the most influential variables.

Estimates of primary and secondary productivity based on fossil algae, fossil cladocera, and sedimentary pigment decomposition products indicated that two periods of high production occurred within Found Lake. The first period was during the "hemlock minimum", when the forests were largely deciduous in character. The second was when man modified the land surrounding the lake in conjunction with the construction of highway #60 and caused the once stable soil components to be quickly eroded. It was proposed that increased availability of phosphorous contributed to both periods of higher productivity.

INTRODUCTION

Incorporated in the sediments that accumulate in a lake basin are the morphological and biochemical remains of numerous plant and animal communities. In the geochemical component of the sediments are the remains of past mineral and nutrient reserves. Together they reflect the past ecological conditions of the lake and its surrounding drainage basin. The sediments therefore hold the potential for interpreting changes in aquatic productivity and in the physical-chemical conditions of both environments.

Limnologists have recognized that lake productivity is affected by the amount of available nutrients entering the system (Likens and Bormann, 1975). Nutrients enter a lake from the atmosphere, through precipitation and wind blown dust and from the soils of the surrounding watershed, via leaching and erosion.

The factors controlling terrestrial nutrient release are complex and not well understood. In a comparison of the major vegetational regions of the USSR, Rodin and Bazilevich (1967) showed that soils from regions of different vegetation types exhibit different nutrient retention characteristics. Likens and Bormann (1974) found significant differences in watershed nutrient losses between several types of undisturbed deciduous and coniferous forests in the United States. It was further hypothesized by Vitousek and Reiners (1975) that watershed nutrient losses are controlled by storage changes within plant biomass as the vegetation undergoes successional development. Mature watershed ecosystems that are no longer adding new biomass and early-successional ecosystems that can not effectively utilize all available nutrients, release higher quantities of essential nutrients than intermediately

aged successional systems that are actively accumulating biomass (Vitousek and Reiners, 1975). Vegetational disturbances whether natural or culturally induced can result in rapid nutrient losses from soils (Davis, 1973). Temperature and precipitation influence the amount of nutrients released by terrestrial ecosystems through their effect on the rate of organic decomposition, rock weathering, and leaching (Williams and Gray, 1974). The geology of the watershed is also of importance. Dillon and Kirchner (1975) reported highly significant differences in total phosphorus export between 34 igneous and sedimentary watersheds in southern Ontario.

The mineral and nutrient load imposed on a lake, then is a function of the geochemistry of its watershed, the hydrology of the region, climate, vegetation and other related natural and anthropogenic conditions. Analysis of sediment biological and chemical components is the key to understanding the complex relationships involved in watershed-lake interactions.

Sediment Accumulation and Time Scale

In order to interpret the rates at which sedimentary events have occurred in the past it is necessary to know the time scale involved. Unfortunately, the amount of information that can be extracted from lake sediment core analysis is frequently limited by the lack of an absolute depth-time scale for the deposits.

Sediment chemical and biological data are most often expressed as percentages. The deficiency with percentage diagrams is that all changes from one level to another are strictly relative. Alternatively

data expressed as concentrations, numbers per unit weight (or volume) of sediment, represent absolute estimates providing that the net thickness of sediment deposited per unit time has remained constant. For the present study this assumption is acceptable for short periods of 20 to 40 years, but can not be assumed when several hundreds or thousands of years are concerned. However, even year to year changes can be significant especially when man has been involved in the area.

Accumulation rates of organisms are most often based on sediment matrix accumulation rates calculated from a number of C^{-14} dates. Davis (1969) determined the sediment accumulation rate for a core from Rogers Lake in southern Connecticut by plotting the radiocarbon ages of 24 levels in the core against depth. The equation of the curve fitted to the points was used to predict the age of a deposit while the slope was used to estimate sedimentation rates. Davis found that the rate of sedimentation varied greatly during the lake's 14,000 year history. A series of C^{-14} dates were obtained by Huttunen et al. (1978) for cores from Lake Lovajari, a eutrophic lake in southern Finland. Dating the profile allowed the authors to estimate the accumulation rates of several chemical and biological components as variables which were independent of both relative changes in species types and of changes in the rate of accumulation of the sediment matrix. Pennak (1963) on several Colorado mountain lakes, Kendall (1969) on Lake Victoria, Wetzel and Manny (1978) on Lawrence Lake, Michigan, and Mott & Farley-Gill (1978) on Maplehurst lake in southern Ontario have all estimated rates of sedimentation by a series of C^{-14} dates. Many other investigator Crisman (1976) have based sedimentation rates for their cores on previously established ages of pollen zone boundaries.

The limitations of the radiocarbon technique in estimating the age of sediments are largely due to uncertainty in the C^{-14} measurements. Contamination of the sample with foreign carbon or the mixing of older carbon in lacustrine materials can lead to inaccurate age determinations. Several investigators have corrected erroneous dates. Davis (1967) revised several inaccurate C^{-14} dates by applying a correction factor based on the difference between her age estimates and those of known pollen transitions.

It has been learned recently that one of the basic assumptions of the radiocarbon inventory of $C^{14}O_2$ is not strictly correct. Comparison of radiocarbon dates with dendrochronologically dated sequoias (Sequoia gigantea) and bristlecone pines (Pinus aristata) indicate that deviations between the two ages, both positive and negative, have occurred in historical time (Ralph et al., 1973). A plot of C^{-14} dates and dendrochronological dates for the last 8000 years enables one to establish calendar ages for C^{-14} dates.

Presently paleolimnologists have made little use of dendrochronology to correct C^{-14} age determinations. The true ages of radiocarbon dated events have been shown to be more accurate when corrected. Support for the dendrochronological corrected C^{-14} chronology comes from other, completely independent sources. Evidence provided by dating layered deposits of annually formed varves indicates that the C^{-14} dates depart from true ages in a manner similar to that of the Sequoia and bristlecone pines (Ralph and Michael, 1974). The corrected radiocarbon dates of 140 artifacts of known Egyptian dynasty ages have shown to be in agreement with their archeologically determined dates (Ralph and Michael, 1974).

For lakes with varved sediments an absolute chronology independent of the standard C^{14} method may be established by counting the discrete annual layers. In practice such annual layers are seldom discernible. A number of instances are known, however, in which annual laminae have proved helpful. Livingstone (1957) used the brown and black banded sediments of Linsley Pond, Connecticut, to determine the accumulation rate (number cm^{-2} year $^{-1}$) of Bosmina for the lake's history. Craig (1972) found almost 5 metres of a 5.6 metre core from Lake of the Clouds to be laminated. The deposition of alternating dark and light layers seemed to be controlled by the annual variation in the supply of organic detritus and precipitated iron oxides (Anthony, 1977). The resulting varve chronology provided a time scale for the study of the vegetational history.

The recent rise in Ambrosia (ragweed) pollen has often been used to calculate the mean sedimentation rate since the onset of cultural activities (Bortleson 1971; Davis 1973). The sudden appearance of high levels of Ambrosia pollen can provide a stratigraphic horizon which can be dated from historical records showing when man moved into the region and began modifying the environment (Davis 1968; Ogden 1967; Bradbury and Megard 1972; Birks et al. 1976). Ambrosia pollen provides a time marker for recent sediments whose ages are not in the practical range of radiocarbon dating techniques.

The use of accumulation rates to interpret paleoecological events is complicated by differential compaction and deposition processes. Sediment focusing, the movement of sediment to the deepest part of a basin or subbasin, can introduce discrepancies between changes in accumulation rates measured directly from sediment cores and actual changes in the

influx of sediment. Lehman (1975) proposed four models for transforming core-measured sedimentation rates into basin wide influx rates. Only his frustrum and hyperboloid models of relatively steep basin lakes predicted differences large enough to cause errors in interpretation, however.

Stratigraphic Indicators of Paleoecological Conditions

Lake basins act as natural sinks for materials produced within the lake as well as materials originating from the surrounding air and watershed. These sedimentary components can be used to interpret paleoecological conditions. The chemistry and minerology of the sediments provide information about source materials, past climates, and general limnological conditions. The morphological and biochemical remains of plants and animals in the sediments and their quantitative relationships give us insight into historical biotic communities and from these much can be deduced concerning the whole complex of ecological interrelationships. As Frey (1974) stated, the task is to "read" the history of the lake-watershed-atmospheric system from the record "written" in the sediments.

Pollen

Paleopalynology provides a means of reconstructing vegetational and climatic history. The method consists of the tabulation of the numbers and kinds of pollen grains in samples collected in vertical sections from sedimentary deposits. The relative frequency of each taxon found in a sample constitutes the pollen assemblage or "pollen spectra" of the sample. On the basis of a series of spectra a pollen diagram can be

constructed. The pollen percentages are presumed to reflect, at least indirectly, the percentages of species in the vegetation that grew in the region at the time when the sediments were deposited. However, a comparison between the modern pollen rain and the vegetation which produced it shows a poor correspondence for almost all taxa. This disparity between species is the result of differential pollen production and dispersal (Livingstone, 1968). An objective interpretation of past vegetational and climatic conditions from pollen diagrams demands an accurate knowledge of the relationship between pollen rain and vegetation. Two methods of providing such knowledge have been developed. One method matches the surface pollen spectra from regions of known vegetation zones with fossil pollen spectra encountered in core analyses. Necessarily it must be shown that the surface spectra from regions of similar vegetation type are reasonably similar to each other and distinctive from other comparable regions of different vegetation. Only then are we justified in assuming that fossil spectra resembling modern spectra were deposited within a similar type of vegetation. Recently Davis and Webb (1975) and Webb and McAndrews (1976) compiled 406 and 606 samples respectively of modern pollen spectra from eastern and central North America. The data were presented as contour maps of percentages of individual pollen types. These "isopol" maps can be used in reconstructing paleovegetation by aiding researchers in locating regions whose modern pollen spectra match fossil spectra.

The second method of transforming pollen percentages into vegetational terms utilizes tree inventory data to determine the ratios or R values between the percentages of each species in the pollen rain and the percentages of the same species in the vegetation. Davis (1963) in

the original case showed that even though the actual R value for a species may vary from one location to another, the ratio of the R values for the various taxa to each other differ little between sites.

Geochemistry

It is generally recognized that lake productivity is affected by the concentration of essential nutrients in a body of water. Among the growth promoting nutrients, phosphorus has been repeatedly demonstrated to be the most important (Hwang et al., 1975). Patalas (1972) demonstrated a significant correlation between the amount of available epilimnetic phosphorus and chlorophyll concentrations for the Great Lakes. Since autotrophic organisms are generally capable of utilizing as much phosphorus as is available to them, an increased supply to the lake should lead to a higher productivity and a more rapid rate of phosphorus sedimentation, provided phosphorus is limiting.

Three major processes are involved in phosphorus sedimentation (cf Mackereth, 1966): 1) precipitation of phosphorus locked into the lattice of fine rock particles; 2) precipitation of phosphorus incorporated in the organic material synthesized both within the lake and within the watershed; and 3) co-precipitation of phosphorus with oxidized Fe, Mn, and Al compounds, these elements having been transported in a reduced form, are then oxidized and precipitated onto the lake bottom.

Mackereth (1966) proposed that phosphorus sedimentation during the late glacial period of three English lakes was accomplished by direct erosive removal. His conclusion was based on the fact that phosphorus concentrations in the clay sediment were close to the average concentration found in igneous rock. The distribution profiles of Fe and Mn

in Ennerdale sediments were inversely correlated with P as the sediment surface was approached. The evidence suggests that rather than being precipitated along with Fe and Mn the sedimentation of phosphorus in the Ennerdale basin was due largely to incorporation into the organic material synthesized in the lake. On the other hand, Mackereth (1966) observed a close correlation between P, Fe and Mn in sediment profiles from Lake Windermere and Esthwaite Water. He explained this as the result of co-precipitation of phosphate with oxidized forms of Fe and Mn. Mackereth (1966) attributed the phosphorus minimum in these cores to direct dissolution of P-Fe complexes during a period of highly reducing conditions in the lake. Once mobile (dissolved) both P and Fe were lost through lake flushing.

The final concentration of phosphorus residing in the sediment of a lake is dependant on the rate of supply of phosphorus to the lake basin, the efficiency of the precipitating mechanisms, and the rate of loss of phosphorus from the recent sediments. Therefore, it is important to examine those factors controlling phosphorus sorption and desorption.

Effect of Hydrogen Ion Concentration

Phosphorus recombination with minerals is largely pH dependant. Maximum uptake of phosphorus has been found to occur at pH 5.5 for soils (Murrmann and Peech, 1969) and pH 5.5 to 6.5 for sediments (MacPherson et al., 1958). Uptake declines rapidly as the pH increases or decreases. Investigations into the mechanism of phosphorus removal from the water column indicate the process is one of precipitation or adsorption depending on polymer size which in turn is controlled by the pH and soluble phosphorus concentration. The slightly acid reaction and dilute

phosphorus solution of common soils and sediments makes adsorption to amorphous Fe, Al and Mn hydroxypolymers the dominant process of phosphorus combination rather than precipitation (Bortleson, 1971).

In lakes characterized by high pH and high concentrations of carbonates (marl lakes) phosphate ion is coprecipitated with monocarbonates (Otsuki and Wetzel, 1972). Precipitation increases with increased pH and is most dramatic above pH 9. High pH micro-environments associated with photosynthesis probably induce phosphate-carbonate precipitation (Otsuki and Wetzel, 1972). The importance of this phenomenon cannot be over emphasized since it appears that the very product of increased productivity (increased pH) acts as a negative feedback mechanism to decrease photosynthesis by reducing the availability of phosphate. Consequently, marl lakes usually have extremely low to moderate algal productivity (Wetzel, 1969). Paleolimological studies on Pretty lake (marl lake) have shown a general inverse relationship between chlorophyll degradation products and carbonate levels of lake sediments (Wetzel, 1970).

Effects of Phosphorus Concentration

Harter (1968) demonstrated the influence of sediment phosphorus concentration on phosphorus dissolution and availability. He showed that the addition of less than 0.1 mg P/g of sediment resulted in the P being strongly bonded with Fe and Al hydroxides. Addition of more than 0.1 mg/g resulted in a more loosely bound form of phosphorus. Harter suggested that large influxes of P to a lake may result in a considerable portion of the P being held in a loosely bound form which would be easily released and made available for biological processes.

Cation Complexing Mechanisms

Bortleson and Lee (1974) examined the adsorptive and desorptive capacity of sediments for added increments of $\text{PO}_4\text{-P}$ in cores containing various amounts of P, Fe and Mn. The results showed a high correlation of Fe and the amount of phosphorus sorbed by the sediment. No such relationship was discernible for Mn suggesting that Fe and not Mn is the dominant factor affecting phosphorus sorption in these sediments. In view of the high Fe:Mn atom ratio in most sediments (e.g., Little St. Germaine Lake, 25:1) the authors believed phosphorus adsorption occurred predominantly with Fe in amorphous Fe-P complexes.

Redox Potential.

Rittenberg et al. (1955) investigated the influence of redox conditions on the distribution of phosphate in the interstitial waters of cores from Catalina and Santa Barbara Basins. The concentration of phosphate in these sediments increased markedly in zones of negative Eh. Savant and Ellis (1964) observed that the solubility of soil phosphorus increased with the development of reducing conditions when the main constituents of soil P was Fe-P. An inverse correlation between phosphate and redox potential was noted for acid loam soils (Mortimer 1941; 1942).

Organic Compounds

Several organic anions have been found to be effective in preventing phosphorus from combining chemically with Fe, Mn and Al. Swenson et al. (1949) noted humus and lignins were effective in replacing P in Fe-P complexes by forming more stable Fe-humus or Fe-lignin bonds. Struthers and Seiling (1950) also found that the most effective P-binding substances were those that formed metal-organic compounds. Of the

organic acids commonly occurring in soil and lacustrine sediment citrate, tartrate, oxalate, malate and lactate were found to be highly effective in complexing phosphorus.

Biological Factors

Benthic fauna and particularly decomposing bacteria influence adsorption and desorption of phosphorus and other nutrient compounds by altering the physical-chemical properties of sediments and transforming organic matter to their smaller more soluble constituents. Kuznetsov (1975) found that different processes of microbial activity created major changes in redox potential and acidity which in turn affected phosphorus exchange rates with the overlying water column. Hayes and Phillips (1958) presented evidence that aquatic bacteria may be competing with the sediments for P by incorporating excessive amounts of phosphorus into organic compounds. Luxury uptake by algae is likewise common (Rhee, 1973). The phosphorus is combined as bacterial and algal protoplasm which acts to increase the net retention time in the water column. This reduces the exchange rate of phosphorus at the mud-water interface by decreasing the amount of phosphorus available for exchange.

Photosynthetic Pigments

Preservation of photosynthetic pigments and their degradation products in aquatic sediments often occur long after the disappearance of the morphological remains of the organisms which produce them. The composition of photosynthetic pigments and their transformation products in lacustrine deposits are largely known (Vallentyne, 1960 and Swain et al., 1964). Degradation products of chlorophylls are predominantly pheophytins, with some chlorophyllides, and increasing amounts of the

further degradational product pheophorbide in the older sediments (Brown et al., 1977). Several carotenoid derivatives including those of the carotenes, myxoxanthin, lutein, rhodoviolascin, and myxoxanthophyll are universally present in organic fresh water sediments (Brown, 1969). Pheophytin and pheophorbide derivatives of bacteriochlorophylls also occur but usually in lesser concentrations. Exceptionally high concentrations have been noted in meromictic lakes (e.g., Little Round Lake, Daley et al., 1977) due to increased preservation in an anaerobic hypolimnion and high annual bacterial biomass. Dickman (1979) found that anaerobic bacteria comprised 60% of the total seston biomass of Pinks Lake, a meromictic lake in Quebec.

Spectrophotometric methods for the quantitative determination of sedimentary chlorophyll and carotenoid degradation products (SCDP) have been applied to investigate stratigraphic patterns of pigment deposition. Evidence indicates that the rate of pigment deposition and the productivity of a body of water are generally correlated (Sanger and Gorham, 1972). Gorham et al., (1974) separated over 30 English lakes into three groups of low, intermediate, and high productivity on the basis of algal standing crop, fertility, and the dissolved ion concentration of the water. Sedimentary pigments increased between 4 and 6 fold from unproductive group 1 lakes to productive group 3 lakes. The strong correlation between pigment concentrations, algal standing crop and other indices of productivity suggest that SCDP analysis is potentially useful as a means of estimating past levels of aquatic primary productivity.

Daley and his associates (Daley et al., 1977) emphasized the use of caution in SCDP interpretations. They reported large discrepancies

in total chlorophyll derivatives from the sediments of Little Round Lake, as determined by SCDP procedure and by paper chromatographic fractionation.

Fogg and Belcher (1961) analysed the distribution of chlorophyll and carotenoid derivatives relative to organic matter in a core from Esthwaite Water. On the basis of marked SCDP changes the authors postulated an early postglacial period in the lake's history characterized by increasing productivity; a mid postglacial period of high and relatively stable productivity; a later period of lower productivity associated with Neolithic forest clearance and a recent eutrophic phase.

Stratigraphic changes in sedimentary chlorophyll and carotenoid degradation products for cores from Pretty Lake (Wetzel, 1970), Berry Pond (Whitehead et al., 1973), Shagawa Lake (Gorham and Sanger, 1976), Galltrasket Lake (Alhonen, 1972), and Lake Biwa (Handa, 1975) have been carefully interpreted as representing changes in past lake productivities.

The usefulness of sedimentary pigments as an index of former levels of aquatic productivity depends on several factors. In order to accurately depict lacustrine productivity, photosynthetic pigments should be largely autochthonous in origin. In paleolimnological studies it is sufficient that the ratio of the various contributing sources should have remained constant with time. Sedimentary contributions of allochthonously produced pigments cannot be easily distinguished from those contributed by aquatic autotrophs.

The amount of allochthonous input is a function of a lake's basin morphometry in relation to its watershed size and slope and the rate of erosion. Moss (1968) showed that allochthonous input can

be significant in small, shallow ponds, however, contributions are usually minimal in bodies of water with a relatively large volume in comparison to its watershed area. The fact that the decomposition of photosynthetic pigments of terrestrial origin is relatively rapid and virtually complete (Hoyt, 1966 a & b) suggests that their relative importance in lake sediments must be minor. The concentration of carotenoid and chlorophyll derivatives in lacustrine sediments is much closer to the concentrations characteristic of phytoplankton seston than those of woodland soils, swamps, and ponds (Gorham and Sanger 1964; 1967; and Sanger and Gorham 1973). Furthermore, investigation of electron-spin-resonance spectra of humic acids in sediments from a mesotrophic lake in Japan, suggested that they are largely aquatic in origin (Otsuki and Hanya, 1967).

Although allochthonous contributions to lacustrine pigment reserves appear to be minimal they may vary substantially during different periods of a lake's history. The ratio of chlorophyll derivatives to carotenoid derivatives may provide an indication of the relative percentage of pigments from allochthonous sources. The significance of the ratio is based on the fact that chlorophylls are preferentially preserved in terrestrial environments while carotenoid preservation is favoured in decaying plankton (Sanger and Gorham, 1972). Relatively low chlorophyll to carotenoid ratios therefore should reflect a smaller proportion of allochthonously produced pigments in the sediments.

Several factors complicate and distort the pigment record making its interpretation subject to skepticism. Photosynthetic pigments are extremely labile and subject to differential rates of diagenesis according to the degree of their exposure to light, temperature, and

oxygen (Brown, 1969). Variations in light and nutrients as well as the age structure of algal populations are closely related to pigment production (Daly and Brown, 1973). Furthermore, it is extremely difficult to separate the contribution of aquatic macrophytes from those of the algae. Aside from the selective processes and in view of the fact that, with the exception of diatoms, few algal species are preserved in sediments, sedimentary pigment analysis provides the best technique for estimating past levels of aquatic primary productivity.

Algal Microfossils

Although phytoplankton generally tend to be poorly preserved in lacustrine sediments, the morphological remains of several algal taxa have been identified. Diatoms (Pennington 1943; Round 1957), and less often chrysomonads (Middlehoek and Wiggers 1953; Nygaard 1956), dinoflagellates (Evitt 1961; Norris and McAndrews 1970) and several members of the chlorococcales group (Deevey 1939; Ouelett and Paulin 1975) are well represented worldwide in freshwater deposits.

Algal fossils, especially diatoms, have often been utilized as a means of estimating past levels of aquatic primary productivity. On the basis of stratigraphic variations in diatom concentrations Round (1957) suggested that several oscillations in productivity had occurred during the postglacial history of Lake Kentmere, England. Bradbury and Waddington (1973) found that influx maxima for diatom microfossils corresponded to periods of increasing productivity in Shagawa Lake. Their influxes were correlated with several indices of eutrophication.

Many algal species are particularly sensitive to changes in the physical-chemical nature of waters. Stratigraphic analyses of species

whose ecological requirements are known can be used to investigate past conditions of pH, temperature, hardness, salinity, and productivity. Assemblage diagrams depicting relative or absolute changes in species concentrations over time form the basis of most paleolimnological investigations.

Interpretation of the changes in diatom taxa recorded in a core from Douglas Lake in Michigan, led Stoermer (1977) to suggest that the lake's development proceeded by a series of stages from a shallow oligotrophic lake to a highly eutrophic one. Haworth (1969) grouped species of similar known ecological requirements; nutrient level, pH, salinity, and habitat, in order to establish whether the changing composition of the diatom community indicated any trends in the past ecological conditions of Blea Tarn, England.

Often paleoassemblage zones are constructed depicting periods of lake history when similar communities and thus similar ecological conditions prevailed. Bradbury (1971) constructed 16 paleoassemblage zones from the fossil diatom record of Lake Texcoco, Mexico. He proposed a complex history of oscillating limnological conditions which were related to water chemistry and lake levels.

Diatoms are not the only group of algae to be useful in paleolimnology. The ecology of several species of Chlorophyta are sufficiently well known that their distribution in lacustrine sediments reflect past lake environments. In an investigation of a core from Potato Lake, Whiteside (1965a) interpreted a change in the composition of Pediastrum species (P. araneosum and P. sculptatum replacing P. boryanum) as indicative of a shift to increasingly eutrophic conditions.

Cladoceran Microfossils

Cladoceran microfossils can, for the most part, be identified to species. Like the algae they are truly aquatic, and therefore provide some of the best insight into past lake conditions. Unfortunately, lower numbers and exoskeleton disarticulation problems make Cladocera more difficult to quantify than diatoms. However, cladoceran remains are found in sufficient numbers in lake sediments for the construction of close interval stratigraphies. Mueller (1964) demonstrated that within reason, deep water sediments integrate seasonal abundance and habitat diversity, so that what is present in the sediments can be considered representative of the entire lake population integrated over time.

Frey (1962) recovered 25 species of chydorid Cladocera from the Eemian interglacial of Denmark and showed that species' morphology have remained stable since that time. Of even greater importance was finding a highly significant correlation between the rank order of these 25 species in the Eemian and their rank order today, the implication being that these species have retained essentially the same ecology and community relationships over at least the last 100,000 years. Therefore, it is reasonable to use their present ecology to interpret past aquatic environments.

Several investigators have suggested that the quantity and type of cladoceran remains in the sediments reflects changes in lake conditions or trophic level (Deevey 1942; Goulden 1964; Deevey 1969; Huttunen and Tolonen 1977; Crisman and Whitehead 1978). In Linsley Pond the concentration of Bosmina remains in the sediment increased exponentially concurrent with an exponential increase in the amount of organic matter

in the sediments (Deevey, 1942). Deevey considered this a response by the cladoceran populations to increasing phytoplankton supply. In a study analysing several cores from Esthwaite Water, Goulden (1964) interpreted four periods of maximum cladoceran concentration as periods of increased aquatic productivity.

Frey (1960) found that the quantity of cladoceran remains in the most recent sediments of four Wisconsin lakes gave some indication of existing production levels of phytoplankton and zooplankton. Crisman (1976) concluded that the concentration of cladoceran microfossils appears to be related to primary productivity. Intuitively a relationship between cladoceran abundance and phytoplankton productivity should hold for any single lake.

Although most cladocera are considered eurytopic, several taxa have sufficiently restricted ecological requirements (stenotypic taxa) to be useful as indicators of past environmental conditions. The replacement of Bosmina coregoni by B. longirostris in lakes undergoing eutrophication has been observed in cores taken from Lake Washington (Edmonson et al., 1956), Linsley Pond (Deevey, 1942), and Bletcham Tarn (Harmsworth, 1968). Likewise Chydorus sphaericus in North America and C. sphaericus and Alona rectangula in Europe appear to respond positively to increasing eutrophication. Both species normally inhabit the littoral community, but when blooms of blue-green algae develop they move into the pelagic zone where they use the algae as a substrate (St. Mikulski, 1978). In Shagawa Lake increased nutrient input associated with the start of hematite mining and forest clearance resulted in large increases in accumulation rates of Chydorus sphaericus and diatoms in the sediments (Bradbury and Waddington, 1973).

With our present state of knowledge, cladoceran response to environmental changes must be judged on a community basis. Decosta (1964) demonstrated the latitudinal affinities of various chydorid species in the surficial sediments of lakes along the Mississippi Valley. He was able to distinguish "northern" species, whose percentage abundance in the taxocene decreased toward the south and "southern" species showing a decrease in percentage abundance toward the north. These latitudinal groupings of chydorids appeared to be delineated in accordance with existing climatic gradients. Latitudinal distribution data of cladoceran species throughout Europe has demonstrated similar climatic associations (Harmsworth, 1968). The cladoceran species as a group appear to be excellent indicators of macroclimatic conditions and when treated statistically should provide a useful means of interpreting relative changes in water temperature and climate during a lake's history.

An ecological analysis of Chydoridae in the lake district of Stechlin, Germany (Flossner, 1964), indicated that Cladocera can also be grouped according to substrate preferences. St. Mikulski (1978) applied this basic knowledge to show the changes in littoral biotopes associates with the complex history of human settlement around Gaplo Lake during the Holocene. Species groups characteristic of muddy and sandy bottoms demonstrated a negative correlation with the percentage of organic matter in the sediments.

Synerholm (1974) examined surficial sediments from lakes along a coniferous-deciduous-prairie vegetational transition in Minnesota. He found it possible to divide the cladoceran species into three distinct assemblages based on correlations of species distributions with lake

conductivity. In a subsequent study on several Minnesota and Florida Lakes, Crisman (unpublished) demonstrated correlations between cladoceran species concentrations in surface sediments and several physical-chemical parameters indicating trophic status.

Our present understanding of European cladoceran ecology is largely due to the efforts of Whiteside (1970) who studied the species composition of chydorid remains in the surficial sediments of 70 Danish lakes of vastly different characteristics. The lakes sampled were grouped subjectively according to seven physical and chemical measurements into one of three groups; clearwater unpolluted; clear water polluted; and ponds and bogs combined. Multiple discriminate analyses were used to characterize 22 of the most common species on the basis of the three established lake groups. In 83% of the cases, the lake type predicted by the chydorid assemblage agreed with the type predicted by the environmental parameters.

Sprules (1977), working with samples from over 100 Ontario lakes, applied principal component analyses to those lakes with similar zooplankton communities in order to determine the limnological attributes common to the lakes of each group. This enabled him to develop a model predicting the limnological characteristics of a lake from a sample of its zooplankton community.

These studies demonstrate that broad environmental controls do indeed govern the composition of crustacean zooplankton communities.

Cladoceran zones are a useful means of delineating major sedimentary changes in cladoceran species composition. They have proved helpful in reconstructing past environmental changes both within the lake itself and in the surrounding watershed. In the past, cladoceran paleoassem-

blage zones have been widely used especially in studies where the cladoceran assemblage changes were not coincidental with pollen zone boundaries (Megard 1964; Goulden 1966; Harmsworth 1968; Whiteside 1970; Crisman 1976).

Historical Studies on Found Lake

Found Lake is considered to be meromictic (Dickman, personal communication) however I believe this is not the case. On several occasions from 1975 to 1977 the hypolimnion was oxygenated. The appearance of sedimentary laminations at many depths however suggests that the lake may have at times become anaerobic by failing to turnover.

A number of paleolimnological studies have been conducted on Found Lake's sediments. Boyko and McAndrews (unpublished) interpreted the regional vegetation history based on the pollen distribution from a deep water core dating back over 10,000 years. A number of pollen zone transitions were dated by radiocarbon techniques. The diatoms and Mallomonas scales from a core used in this study indicated interesting changes had occurred in the plankton communities of the lake (Smol, 1979). Several significant changes occurred in the last century as the result of perturbations caused by the construction and paving of highway 60. In another study (Dillon, unpublished), the sediment geochemistry revealed recent changes in the input of chemical elements to the lake. Many elemental concentrations increased in the sediments as the direct result of the "acid rain" phenomenon (Dillon, personal communication).

Research Purpose

The present investigation was undertaken to determine the influence of watershed vegetation, soil, and climatic changes on nutrient availability and ultimately lacustrine productivity in Found Lake, Ontario, during its 11,800 year history. It was the purpose of this study to examine as many relevant lines of evidence as possible in order to help elucidate the complex mechanisms thought to be involved in regulating nutrient availability and productivity within aquatic ecosystems. To accomplish this, pollen analysis was utilized as a means of delineating post glacial vegetational and climatic changes for the Found Lake watershed, while analyses of sediment chemistry provided insight into temporal changes of watershed nutrient release and availability to aquatic autotrophs. Lacustrine primary productivity levels were estimated by accumulation rates of selected algal remains, organic matter, total carbonate content and photosynthetic pigment degradation products. Levels of aquatic secondary productivity were defined by cladoceran accumulation rates.

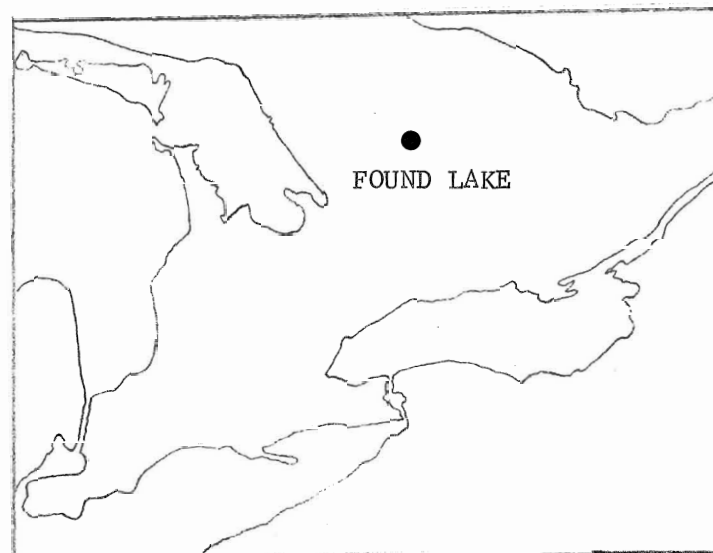
In light of known species and community ecological requirements, analyses of algal and cladoceran paleoassemblage zones have provided evidence for the changing physical and chemical nature of the lake.

SITE DESCRIPTION

Found Lake ($45^{\circ} 33'N$, $78^{\circ} 39'W$) is a small oligotrophic lake of glacial origin located in the Laurentian Range of Peck township, Ontario (Figure 1). It lies in southwestern Algonquin Park, 100 metres south of the park museum on highway 60.

The lake has a surface area of 0.13 km^2 , volume of $1.5 \times 10^6 \text{ m}^3$ and a mean depth of 11.6 metres (Scheider, 1978). The watershed has an area of 0.10 km^2 and is underlain by metamorphic migmatite formed during the Precambrian Era. The pegmatite and gneisses comprising the migmatite consist mainly of pink feldspar, grey quartz and minor black biotite and hornblende (Guillet, 1969). The bedrock is mantled by varying depths of silty sand, sandy loam, and coarse to fine sands. The soils of the region are classified as orthic podzols, low in fertility and inclined to droughty conditions (Richards, 1965). The vegetation of this region, the Laurentian Uplands, has been classified by Braun (1964) as a hemlock-white pine-northern hardwood forest.

Figure 1: Location and morphometric map of Found Lake,
south-central Ontario taken from Scheider (1974)
The location of the core site is also indicated.



● CORE LOCATION
CONTOURS IN METRES

250 metres

EXPERIMENTAL METHODS AND PROCEDURES

A modified Livingston coring device (Wright et al., 1975) was used to remove a 2.85 metre long core from a site located near the deepest point in Found Lake (Figure 1). The core was taken on the 11th of February 1977 and extruded on the following day in the laboratory where it was photographed and its composition, colour, and texture were described.

Comparison of the diatom distribution in this core with shorter cores taken with a K-B surface corer (Smol, 1979) indicated that the uppermost 4-6 cm of the sedimentary column was not collected. Furthermore, the white line produced by materials deposited while highway 60 was being paved in 1948 was missing from the livingston core.

The core was marked at 5 cm intervals and 1cm long cross sections centered at the 5 cm interval mark were removed from each of these levels. The samples were freeze dried for 48 hours, weighed, and homogenized by mixing with a spatula. Replicate subsamples were analyzed to ensure homogeneity.

Analytical Procedures and Apparatus

Pollen Analyses

Samples for pollen analyses were prepared by a method modified from that of Erdtman (1943). The procedure has been summarized as follows: Successive treatments with hot 10% KOH for 15 minutes, hot 10% HCl for 5 minutes and hot 50% HF for 20 minutes. This was followed by dilution with glacial acetic acid, centrifugation and acetolysis treatment at 100°C for 2 minutes. The final sediment residue was mixed with a small amount of Hoyer's solution (Appendix I) until homogeneous. The pollen slurry was then transferred onto a glass slide and a no. 1 thickness coverslip was applied. A detailed procedure for the preparation of sediments for pollen analysis is given in appendix II.

Pollen estimates were based on the mean percentage of counts from

two slides. Each slide was traversed at 400 X magnification until 350 to 400 pollen grains had been counted. The percentage representation of each species was based on the sum of the total arboreal and shrub pollen counted as has become the customary practise (Maher, 1977).

Sediment Physical and Chemical Analyses

Samples were individually weighed on a Mettler Type H6 balance before and after freeze drying to determine the sediment water content. Percent organic matter was determined from the weight loss by ashing the freeze dried samples at 550°C for one hour. The percent total carbonate in the sediments was determined by dividing the percent weight loss on ignition between 550°C and 1000°C by 0.44, (the fraction of CO_2 in CaCO_3 (Dean, 1974)). Organic matter and total carbonate were expressed as a percent of the dry weight of the sample and as annual weight accumulated ($\text{g deposited cm}^{-2} \text{ year}^{-1}$).

Sediment chemistry was determined by utilizing both atomic absorption and colorimetric techniques. Atomic absorption procedures were used for iron, manganese, potassium and aluminum while phosphorus was analysed by the vanadomolybdophosphoric yellow colour method (Jackson, 1958).

Depending on the amount of available sediment, two to four subsamples were taken at 5 cm core intervals and prepared for chemical analyses by: 1) ashing the sediments in a muffle furnace at 550°C for one hour; 2) finely grinding the ashed sediments; 3) adding 3 to 5 ml of perchloric acid to a polypropylene digestion chamber; 4) heating the liquid at approximately 90°C until almost entirely evaporated; 5) adding 10 ml of 50% HCl and heating gently (70°C) for 10 minutes

followed by a cooling period of one hour; 6) filtering the residual liquid through Whatman no. 7 filter paper and pouring the filtrate directly into a 50 ml volumetric flask; 7) making the solution up to 50 ml with distilled water.

Iron, manganese, potassium, and aluminum concentrations were determined by aspiration of the digested solution into a Perkin-Elmer model 403 atomic absorption spectrophotometer. Calibration curves for each element were established by analysing a series of standard solutions. Appendix I gives the chemical formula for the preparation of the standard solutions of Fe and P. Commercial standardized solutions were obtained for Al, K and Mn (Fisher Scientific Co.).

To analyze total sedimentary phosphorus, aliquots of the original digestion were pipetted along with 10 ml of vanado-molybdate reagent (see appendix I for chemical formula) into a 50 ml volumetric flask and diluted to 50 ml with distilled water. After allowing at least 15 minutes for full colour development, the absorbance of the solution was measured on a Bausch & Lomb 100 spectrophotometer at a wavelength of 440 nm. This wavelength was suggested by Jackson (1958) for working concentrations from 2.0 to 15.0 ppm phosphorus, which was the typical range encountered in this experiment. A sample of distilled water was digested in the same manner as the other samples and used as a

The vanadomolybdophosphoric acid method was chosen for sediment P analyses because of its high sensitivity within a wide range of concentrations (1 to 20 ppm of P), colour stability, and freedom from interference with a wide range of ionic species (Jackson, 1958). The final acid concentration was maintained between 0.5 N and 1.0 N. Jackson (1958) found that outside this range the relationship between

phosphorus concentration and colour development was no longer linear.

Generally, inorganic orthophosphate is either extracted by micro-organisms in which case it is likely deposited as organic forms of solid phases of hydrated iron, manganese and aluminum oxides which are quickly sedimented (Mackereth, 1966). The higher the concentration of metal hydroxides in the waters the greater the amount of hydrated metal oxides. Phosphorus vs. metal ratios may possibly provide an indication of the amount of orthophosphate initially taken up by aquatic life. The author suggests that relative changes in the ratio may be interpreted as changes in the amount of "available phosphorus".

Extreme caution should be exercised if phosphorus vs. metal ratio are to be utilized in such a manner. Mineralization of organic phosphorus and dissolution of sorbed inorganic phosphate both tend to complex the sedimentary record and make interpretations difficult.

Analysis of Sedimentary Pigments

Photosynthetic pigments were analysed according to the methods outlined by Vallentyne (1955) and Sanger and Gorham (1972). Each sample was combined with 90% acetone, agitated and allowed to stand for 24 hours to ensure a high efficiency of pigment extraction. This mixture was then filtered using Angel Reeve no. 934 AH glass fiber filters.

Absorbance of the total filtrate was then measured on a Hatachi model 124 spectrophotometer at 667 nm for chlorophyll derivatives and 450 nm for carotenoid derivatives. Because extraneous compounds may also contribute to absorbance at the red peak for chlorophyll derivatives, a correction for background absorbance, measured at 580 nm, was subtracted from the chlorophyll peak (Appendix III). Pigment concentrations were expressed as units of sedimentary chlorophyll and carotenoid degradation products (SCDP) per gram dry weight of sediment, one SCDP unit being equivalent to an absorbance of 0.1 in a 1.0 cm cell when dissolved in 10 ml of 90% acetone solvent (Vallentyne, 1955).

Diatom Analysis

The analysis of sedimentary diatoms was conducted by John Smol. A description of the methods used are provided in his M.Sc. theses (Smol, 1979).

Algal Analyses

Several species of algae belonging to the group Chlorophyta were preserved in the sediments. The methods used for their preparation and enumeration were identical to those followed for the Cladocera.

Cladoceran Analysis

Samples were taken at 10 cm intervals from the core and prepared for algal and cladoceran analysis according to the methods of Crisman (1976). Procedures included: 1) suspending the sediment in hot 10% KOH solution for 30 minutes; 2) boiling the sediment in 50% HF solution for 30 minutes; 3) gently heating the sediment (70°C) in 10% HCl solution for 10 minutes; 4) filtering those samples having a high silt or clay content through a 35 μm mesh phosphobronze sieve. The sediment residue was then decanted and combined with a measured volume of tertiary butyl alcohol (TBA). For a detailed procedure of the methods used for preparing sediments the cladoceran analysis see appendix II.

Slides were prepared by delivering a known aliquot (50 μl to 1000 μl) of the final TBA mixture onto a drop of silicon oil positioned in the center of a heated glass slide (75 to 80°C). A coverslip was added and secured at each corner with nail hardener. This was done to make certain that none of the cladoceran remains could shift, thus ensuring that no remains were missed or counted more than once.

Fossil cladoceran remains were counted using a Nikon Phase Contrast

microscope at a magnification of 400 diameters. An oil immersion lens (1000 X magnification) was used for more difficult identifications. Identified species were recorded along with their location (slide coordinates), skeletal remain category, and degree of fragmentation. Two entire slides were counted for each sample analysed and there were never less than 300 cladoceran remains per slide.

Paleovegetation

Pollen production and dispersal mechanisms vary such that the percentage contribution of each species to the total pollen sum is different from their corresponding representation in the vegetation. An attempt has been made to correct for this by establishing a ratio between the representation of a species in the present vegetation and its pollen contribution in local sediments. Conforming to Davis' original work in 1963 the letter R was used to designate this ratio.

Forest stand maps covering an area of 230 km² centered around Found Lake were used to calculate the percentage representation of each species in the vegetation. The maps were prepared by the Ministry of Natural Resources from forest inventory surveys which were conducted between 1958 and 1961. (Department of Lands and Forests, 1958 to 1961).

Four pollen slides each were prepared and counted from the surface sediments of Found Lake, Jake Lake, and Delano Lake. Jake and Delano Lakes are both located within 2 km of Found Lake but in different watersheds. The surface pollen percentages for all three lakes were averaged and then used to calculate the R values for those taxa which were adequately represented in both the modern vegetation and recent

pollen rain. The author felt that averaging the lakes would provide more accurate estimates for the entire region (230 km²). Otherwise, disparities between the local Found Lake vegetation and the regional vegetation would have lead to erroneous estimates of R.

The R values obtained were used to prepare a paleovegetation diagram for the Found Lake core. Estimates of the percentage representation of each species during specific periods of Found Lake history were accomplished by multiplying their normalized R values by their respective fossil pollen percentages and expressing this as a percent of the total for all tree and shrub species. The R values were normalized by dividing by a common R value (Davis, 1973).

Rate Calculations

Sedimentation Rate

Rates of sedimentation were established from the depth-time relationship of the Found Lake core. Six radiocarbon and three additional dates were used to establish a sedimentary time scale. These radiocarbon ages were those calculated for pollen zone transitions from Found Lake (McAndrews, unpublished). The three additional dates used were: 1) a historical date of 100 Y.B.P. for European forest clearance placed at the Ambrosia horizon; 2) a date of 450 Y.B.P. for the lower boundary of zone 3d based on the varve chronology of Found Lake (McAndrews, unpublished); and 3) a date of 11,800 Y.B.P. for the deglaciation of the southern Lawrencian Highland (Prest, 1970).

Microfossil and Chemical Accumulation Rates

The accumulation of microfossils on the lake bottom were estimated

on the basis of sediment matrix deposition rates (cm yr^{-1}) and concentrations (g cm^{-3}) of the various fossil components. All calculations whether biological or chemical, were expressed in terms of the units of each deposited per cm^2 of lake bottom per year.

This technique of estimating accumulation rates (i.e., based on the total weight of the sample) has not been utilized before this study. Previous methods all based on a 1 cm volume of sediment were subject to sampling compaction and other small volume measurement problems which do not affect the total weight based calculations.

Calculation of Cladoceran Individuals

Following death and molting, cladoceran exoskeletons usually disarticulate into head shields, shells, ephippia, postabdominal claws, postabdomens and antennal segments. Each of these component parts undergoes further post-mortem fragmentation; the degree of which depends on the individual characteristics of the species, sediment grain size, and the degree of sediment mixing (Frey, 1976). In order to estimate the concentration of cladoceran numbers in the sediments it was necessary to determine how many cladoceran individuals were represented by the fragments found in each sample.

For the purpose of estimating numbers of individuals both whole and fragmented remains were used. It was assumed that two fragmented remains equalled a whole remain. This procedure first introduced by Crisman (1976) has been refined somewhat in this study to compensate for gross differences in the fragmentation rate of remains from one level to another. Where the percentage of fragmented remains departed significantly

($p > .05$) from the core mean a correction factor was used to adjust the estimates at those levels. It was only necessary to correct values at 240, 250 and 260 cm. Fragmentation rates at these levels increased by over 30 percent.

Establishment of Floral and Faunal Assemblage Zones

Paleoassemblage zones were established to distinguish periods of Found Lake history characterized by similar communities of plants and animals. Core levels with communities statistically different from those found at the next younger level closer to the surface were designated a zonal boundary.

The zonations in the present study were established quantitatively on the basis of results from product moment and Spearman's ranked correlation coefficients (Siegel, 1956). Zonal boundaries were defined by pronounced declines in correlation coefficients comparing stratigraphically adjacent assemblages (i.e., levels 260 vs 250, 250 vs 240 ...etc). As used here these coefficients represent a measure of community similarities (Yarranton and Ritchie, 1972).

Data Analyses

Sampling and counting errors for all core analyses were estimated using standard statistical methods. The mean and sample standard deviation were calculated for each core level where replicate determinations were performed. Where three or more replicates were analysed 95% confidence intervals were calculated. The mathematical formulae

for all statistical tests are given in appendix IV.

The significance of results from Spearman's ranked correlation program were tested by computing the student-t value (t_s) associated with each observed correlation coefficient (r_s) and then comparing that t-value with the appropriate value in the student-t tables for a two-tailed test. For linear regressions, observed correlation coefficients were compared with the critical correlation coefficients listed in Table A-11 of Snedecor and Cochran (1967).

Regression analysis was utilized to investigate possible correlations between indices measuring watershed vegetational composition, nutrient release (sediment chemical storage), and aquatic productivity. Past vegetational changes were quantified using Pearson's product-moment analysis to compare differences in species formulated as a measure of the degree of change in the vegetation from one core level to the next. Product-moment correlation coefficients were calculated for all possible combinations of 1-r pollen, chemical elements, photosynthetic pigments and biological microfossils.

Further, all analyzed sediment core components were grouped according to the established pollen zones and their means were compared statistically. This served to demonstrate whether the levels of a particular component were statistically different under the various vegetational environments known to have occurred around the lake since its inception. Pollen zone means were compared using student-t values determined by either of two formula. The formula used depended on whether the F tests indicated equal or unequal variance between means (see appendix IV).

Although data screening indicated that the results were not normally distributed, parametric statistics were chosen to evaluate most of the analyses. There were several reasons for not conforming to the assumptions of these tests. The methods used are particularly resilient to non-parametrically distributed data (Snedecor and Cochran, 1967) and it was felt that given a larger sample size the data would have more closely approached a normal distribution. Furthermore, these statistical methods have been used widely in similar paleolimnological studies without adhering to their assumptions.

RESULTS

Pollen and Spore Analysis

A palynological investigation of the Found Lake core was conducted as a means of interpreting the past vegetational history of the region and to provide a chronology for watershed-lake events. The percentage pollen and paleovegetation diagrams for Found Lake are presented in figures 2 and 3 respectively. Eight paleovegetation assemblage zones and subzones (pollen zones) have been established for the Found Lake core: Zone 1 (2.6 - 2.4 metres) forest - tundra; Zone 2a (2.4 - 2.1 metres) open forest-jack pine - spruce dominant; Zone 2b (2.1 - 1.85 metres) mixed forest - white pine dominant; Zone 3a (1.85 - 1.6 metres) mixed forest - white pine - hemlock - hardwoods assemblage; Zone 3b (1.6 - 1.1 metres) white pine - maple - beech assemblage; Zone 3c (1.1 - 0.2 metres) hemlock - maple - beech assemblage; Zone 3d (0.2 - 0.1 metres) hemlock - spruce - beech assemblage; Zone 4 (0.1 - 0.0 metres) disturbed zone - herbs assemblage. Paleovegetation zones, their major palynostratigraphic aspects, and an interpretation of the prevailing climate corresponding to each pollen zone is provided in table 1.

Zone 1 (2.6 - 2.4 metres)

The basal assemblage zone, pollen zone 1, spanned the period from about 11,800 Y.B.P. (Prest, 1970) until 10,600 Y.B.P. This zone which best describes a forest - tundra community was characterized by high percentages of non-arboreal pollen (Fig. 2) and high percentages of spruce (Picea) in the vegetation (Fig. 3). Sedge (Cyperaceae), sage (Artemisia), and shrub willow (Salix) attained their maximum percentages

Figure 2. Trees, shrubs, herbs, pteridophytes, and aquatic angiosperm spore and pollen diagram depicted as a percentage of the tree and shrub pollen sum.

FOUND LAKE, Peck County, Ontario

POLLEN AND SPORES

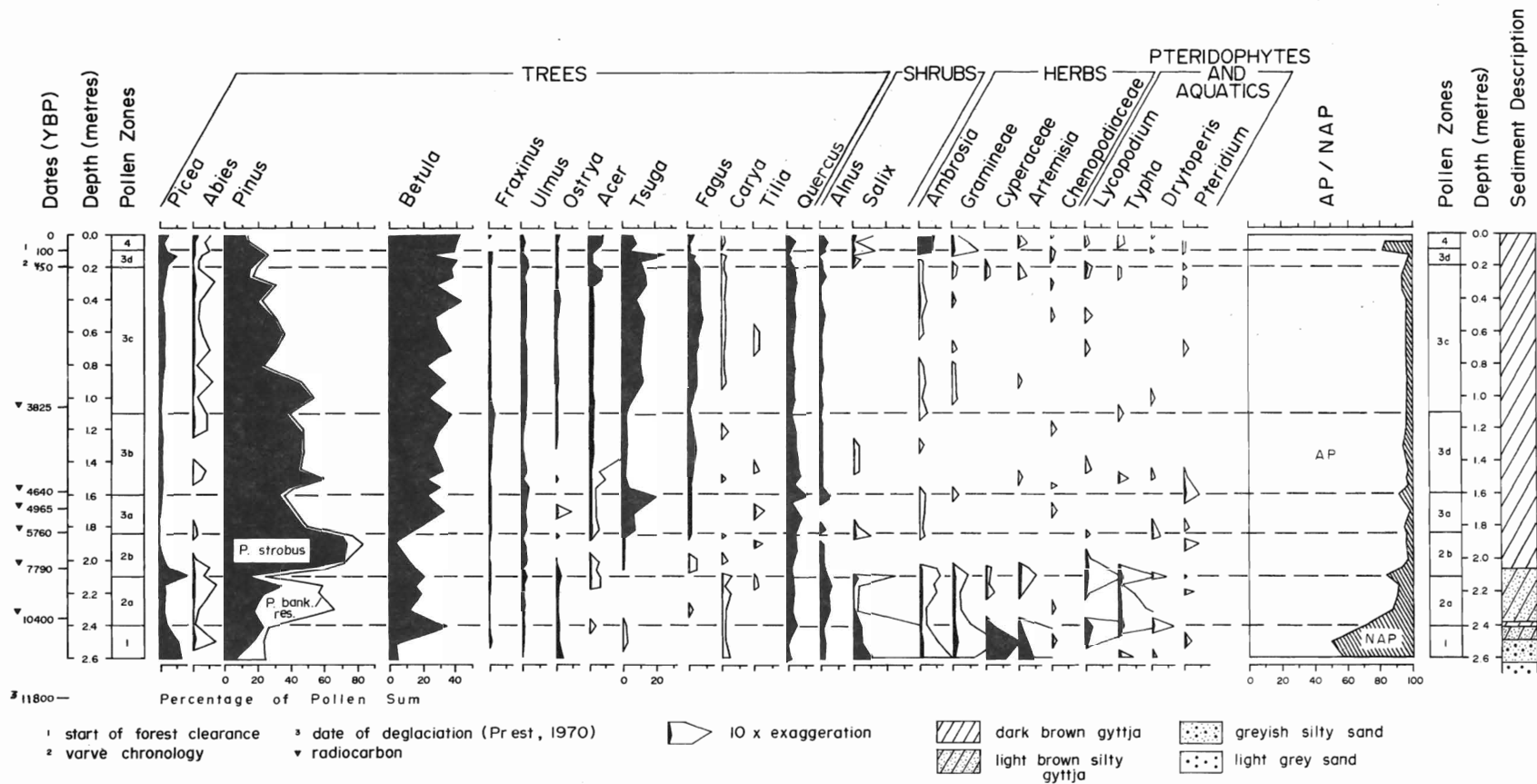


Figure 3. Percent paleovegetation diagram for Found Lake, Ontario.

FOUND LAKE, Peck County, Ontario

PALEOVEGETATION

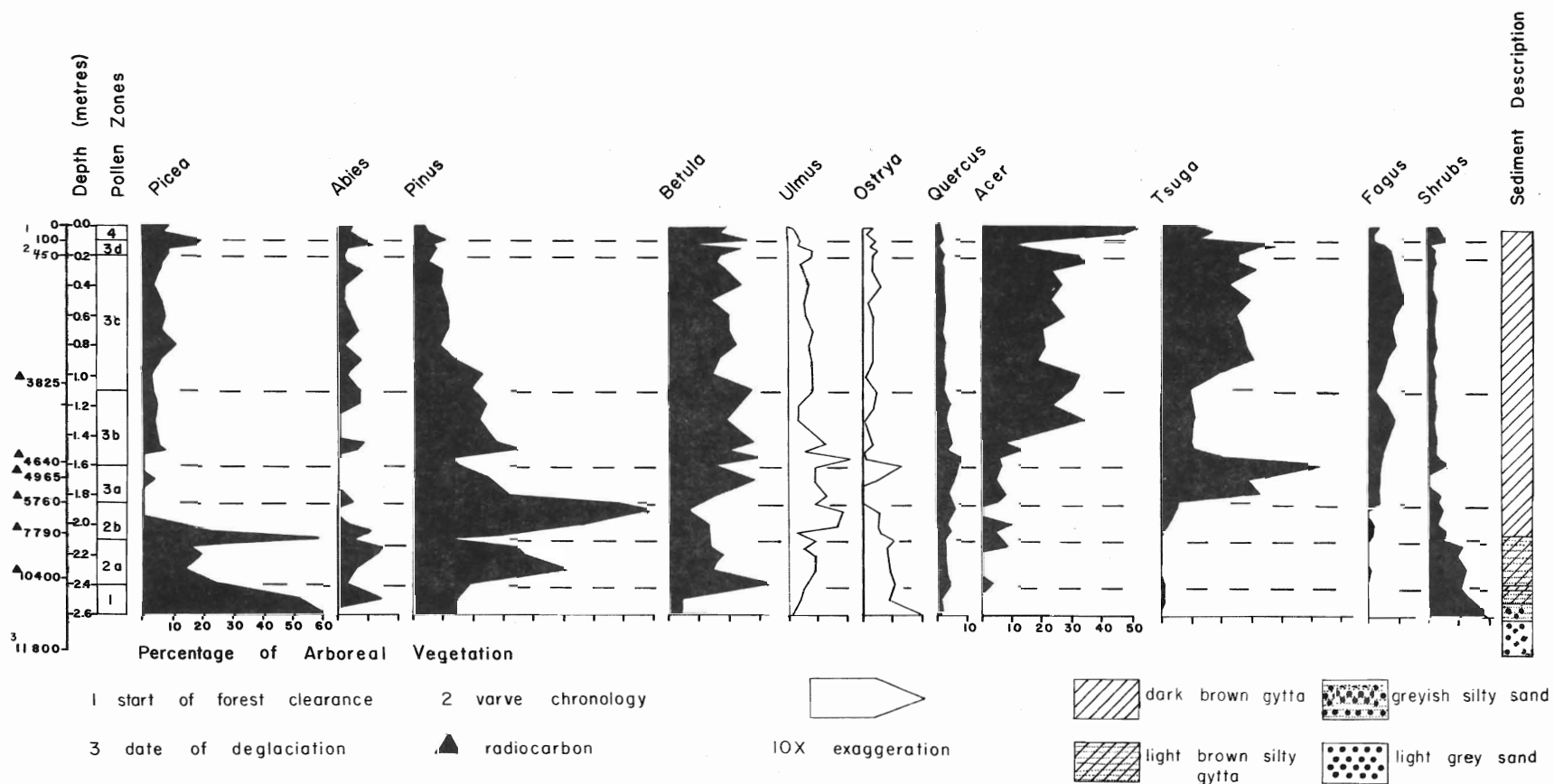


Table 1: Paleovegetation Zonation for Found Lake, Ontario				
Time Scale (years B.P.)	Pollen Assemblage	Paleovegetation	Major Palynostratigraphic Characteristics	Climatic Interpretation
100 450 3900 4700 5700 7900 10300 11800	4	Disturbed Environment	Increased ragweed and grass pollen; Decreasing pine, spruce, beech, and hemlock	Present Climate
	3d	Mixed Coniferous Deciduous Forest	Maximum hemlock and increased spruce; Decreased beech and hemlock.	Cooler and Moist
	3c		Increased hemlock and beech; Declining pine.	Warm and Moist
	3b		Decreased hemlock; Increased pine and beech.	Warm and Dryer
	3a		Increased hemlock, beech, and maple.	Warmer and Moist
	2b	Boreal Forest	Pine dominant (predominantly white pine); Declining per- centages of birch and alder.	Increasing warmth; Drying trend continues
	2a		Pine dominant (predominantly red and jack pine); Increasing alder; Declining sedge, sage, and willow pollen.	Drying and Warmer
	1	Forest-Tundra	High percentages of <u>Cyperaceae</u> , <u>Artemisia</u> , willow, and spruce pollen.	Cold and Moist ↑ Cold and Dry
		Deglaciation		

in zone 1. Found Lake influx data for a core analyzed by Boyko and McAndrews (unpublished) indicated that absolute pollen frequencies (APF) were extremely low during this period.

Zone 2a (2.4 - 2.1 metres)

Extending from 10,600 to 8,100 Y.B.P. pollen zone 2a was characterized by high percentages of jack pine (Pinus banksiana) and alder (Alnus). The lower boundary of this zone was defined by low spruce and herb pollen and rising percentages of jack pine and alder (Fig. 2). The upper boundary corresponded to a peak in spruce, and low jack pine representation (Fig. 3). The pollen of a few temperate taxa, oak (Quercus), elm (Ulmus), and hophornbean (Ostrya) were present in trace amounts and the arboreal pollen content increased. Boyko and McAndrews (personal communications) reported higher APF values for the same period (zone 2a) in their Found Lake core.

Zone 2b (2.1 - 1.85 metres)

The period of lake history from 8,100 to 5,700 Y.B.P. was represented by Zone 2b. The lower zonal boundary was delineated by rising percentages of white pine and declining percentages of spruce (Picea) and birch (Betula) pollen. The upper zonal boundary was defined by increasing birch and decreasing pine percentages. Low values of non-arboreal pollen (Fig. 2) and the highest total APF values (McAndrews, personal communications) for the core were characteristic of this zone. There was also during this period a further increase in many mesophytic taxa, e.g., elm (Ulmus), hemlock (Tsuga) and beech (Fagus).

Zone 3a (1.85 - 1.6 metres)

Zone 3a, spanning the interval from approximately 5,700 to 4,600

Y.B.P. was dominated by hemlock and white pine (Pinus strobus). Several hardwood trees such as maple, (Acer), and beech comprised a minor component of the mixed forest (Fig. 3). The lower boundary of this zone was defined by declining pine and rising hemlock, birch, and beech percentages while the upper boundary was based on a rapid decline in hemlock and increasing percentages of pine. The period marked the first significant contribution of deciduous mesophytic species to the forest vegetation.

Zone 3b (1.6 - 1.1 metres)

The period of Found Lake history from 4,600 to 3,800 Y.B.P. was characterized by minimal hemlock and higher percentages of maple, pine, and spruce.

Zone 3c (1.1 - 0.2 metres)

The period from 3,800 to 450 Y.B.P. was distinguished by maximal beech and high percentages of hemlock, maple, birch and spruce. Pine representation declined to its lowest core level near the end of the zone.

Zone 3d (0.2 - 0.1 metres)

Extending from about 450 to approximately 100 Y.B.P. this zone was characterized by a small but significant increase in the percentage of pine and spruce and a decrease in such thermophilous taxa as beech and maple. Hemlock representation was maximal during this period. The date for the start of this period was based on the varve chronology of the Found Lake core provided by McAndrews (unpublished). The age corresponded closely to the date estimated for the same zonal boundary in a core from Crawford Lake (Boyko, 1973).

Zone 4 (0.1 - 0.0 metres)

A sharp rise in the percentage of ragweed (Ambrosia), grass (Graminae) and other herbaceous pollen together with declining percentages of pine, hemlock, beech and elm characterized zone 4. The lower boundary which coincided with the start of forest clearance and agriculture has been tentatively assigned a date of about 100 Y.B.P.

Sediment Description

The stratigraphic changes in sediment colour, grain size, and lithology for the Found Lake core are described in Table 2. Sediment examination indicated a light grey coloured sand was deposited immediately after deglaciation. During the latter half of zone 1 through to early zone 2b a greenish brown, silty gyttja was present. Inorganic sedimentation was interrupted at the pollen zone 1/2a transition by a thin layer (1.0 cm) of darker, organic rich, gyttja. The remainder of the core consisted of a greenish brown, algal gyttja with the occasional appearance of faint laminations.

The upper 10 cm of the core was black in colour. The blackish appearance was probably either the result of manganese dioxide or iron sulphide in the sediments. The phenomenon was most prominent at the 5 cm level and nearly absent in the surface 2 centimetres.

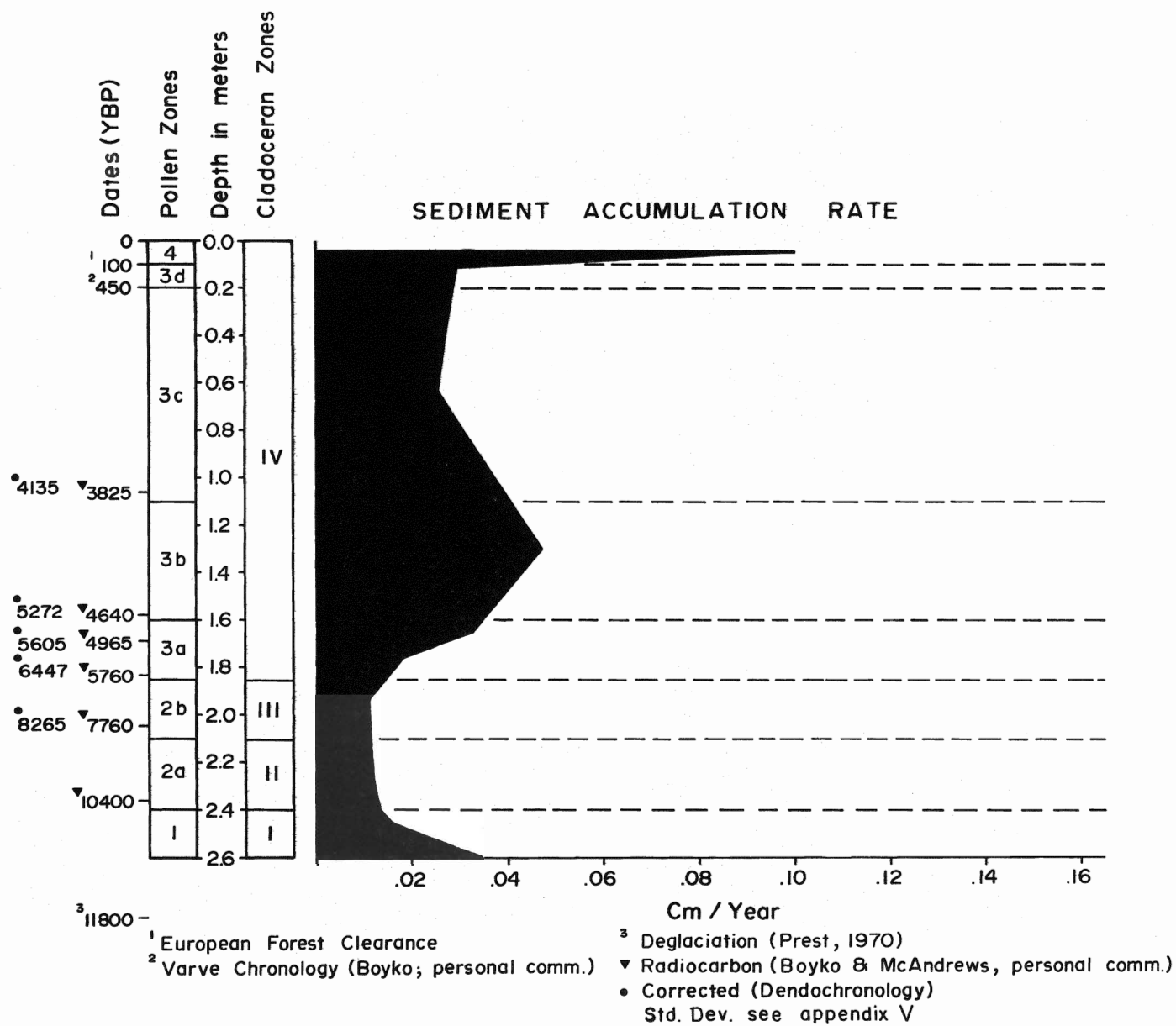
Sediment Matrix Accumulation

Sedimentation rates for the Found Lake core (Figure 4) varied substantially during the lake's ontogeny. Initially, sediment accumulation rates in the basin were high but values quickly declined during pollen zone 1 and remained relatively low throughout zones 2a and 2b.

Table 2: Found Lake sediment stratigraphy.

<u>Sediment Depth</u> (cm)	<u>Description of Sediment</u>
0-10	Blackish brown gyttja
10-15	greenish brown gyttja; numerous coarse organic fragments present, less compacted sediments
15-182	greenish brown gyttja; faint laminae present; coarse organic fragments and leaf remains occasionally present
182-197	greenish brown to greenish black gyttja with some coarse organic fragments
197-206	greenish brown gyttja; laminae; predominantly organic
206-239	medium greenish brown, silty gyttja; higher organic content but still highly siliceous
239-240	brown gyttja
240-244	greenish brown, silty gyttja
244-245	light grey sand
245-262	greenish brown silt; some organic content, mostly siliceous
262-285	light grey sand, very little organic content; highly siliceous

Figure 4. Sediment matrix accumulation rate diagram for the Found Lake core.



The latter phase of pollen zone 2b marked the beginning of a gradual increase that reached a postglacial maximum in zone 3b. Subsequently, accumulation rates declined and remained relatively constant until zone 4 (disturbed zone) when sedimentation rates increased suddenly to a historical peak.

Geochemical Analyses

Analysis of stratigraphic changes in lake sediment chemistry were performed to interpret changes in watershed nutrient release and nutrient availability to aquatic autotrophs.

Sediment Organic Matter and Total Carbonate

Stratigraphic changes in the accumulation rate of organic matter and total carbonate (Fig. 5) have been utilized to estimate variations in aquatic productivity. Except for a peak in total carbonate at 2.4 metres the accumulation rate of organic matter and total carbonate was low until the end of pollen zone 2b. The development of a mixed forest in pollen zone 3a coincided with the beginning of a period of generally increasing values which peaked during the hemlock minimum. Accumulation rates of both organic matter and carbonate declined in zones 3c and 3d. Total carbonate estimates for the disturbed zone were not available as the samples were spilled after ashing at 1000⁰ C. Organic matter however increased exponentially during this period.

Phosphorus and Iron

The phosphorus and iron accumulation rate curves for the Found Lake core were remarkably similar (Fig. 6). Both were initially high but declined quickly during pollen zone 1. Sediment influx of these

Figure 5. Accumulation rates of organic matter and total carbonate expressed as mg deposited per cm^2 of lake bottom per year.

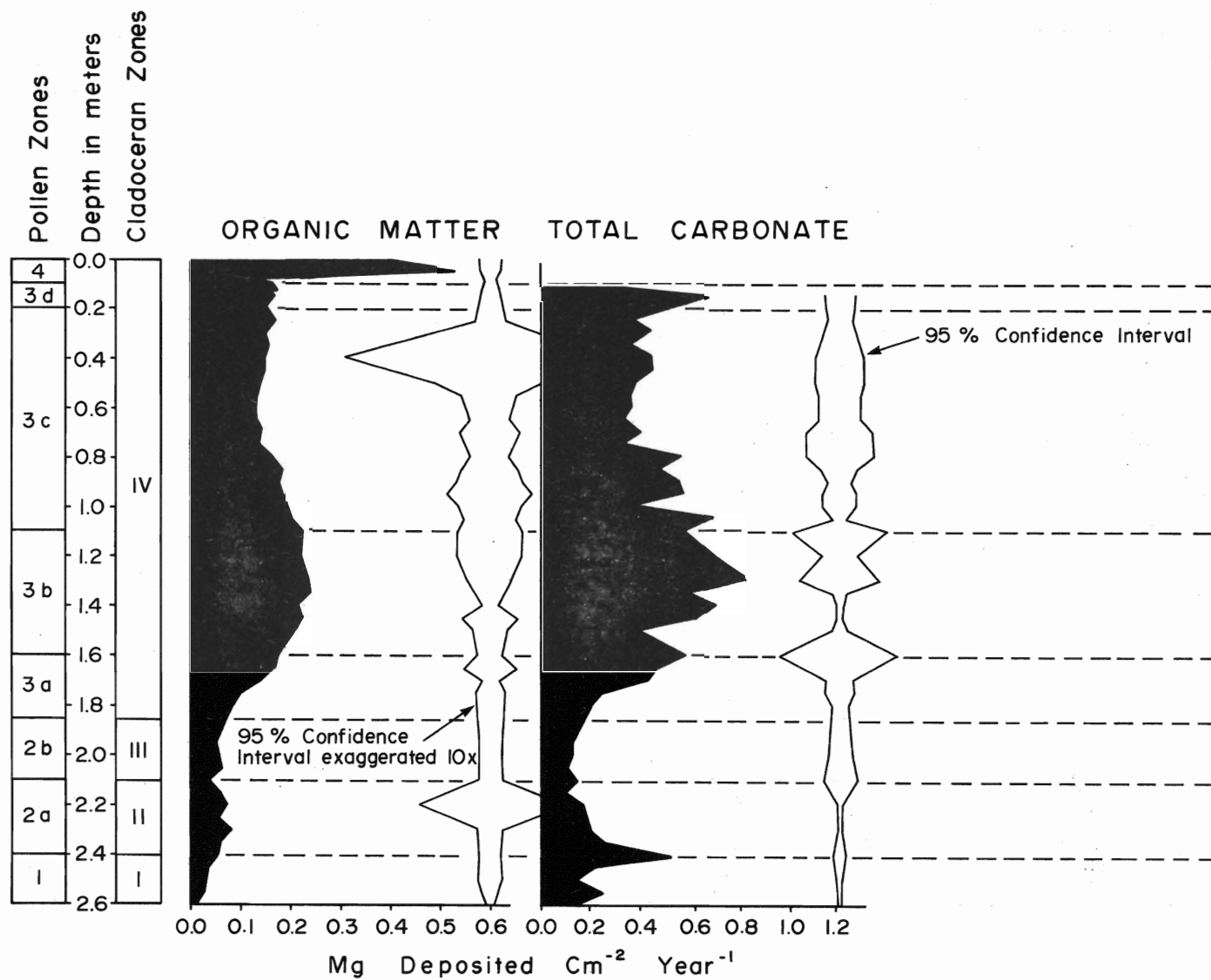
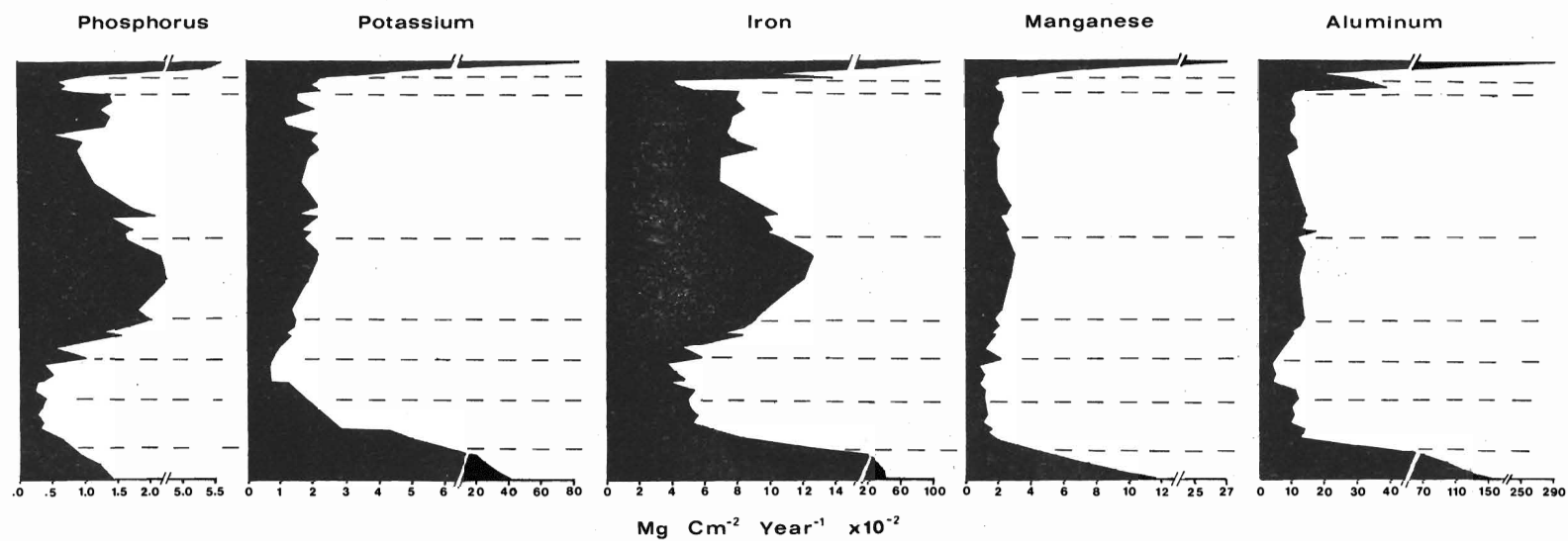


Figure 6. Sediment accumulation rates of phosphorus, potassium, iron, manganese, and aluminum in the Found Lake core expressed as mg deposited per cm² of lake bottom per year.

Pollen Zones
Depth in meters
Cladoceran Zones

4	0.0	
3d	0.2	
	0.4	
3c	0.6	
	0.8	
	1.0	IV
	1.2	
3b	1.4	
	1.6	
3a	1.8	
	2.0	III
2b	2.2	
	2.4	II
2a	2.6	
1		I



elements was low during zone 2. They began to increase early in zone 3a and produced a mid core peak during the "hemlock minimum" (zone 3b). Following this period levels declined quickly and remained relatively constant until the end of pollen zone 3c while phosphorus declined more gradually to the 45 cm level then increased and remained high from 40 to 20 cm. Subsequently, accumulation rates declined in zone 3d then increased to a core maximum in zone 4.

Manganese, Potassium, and Aluminum

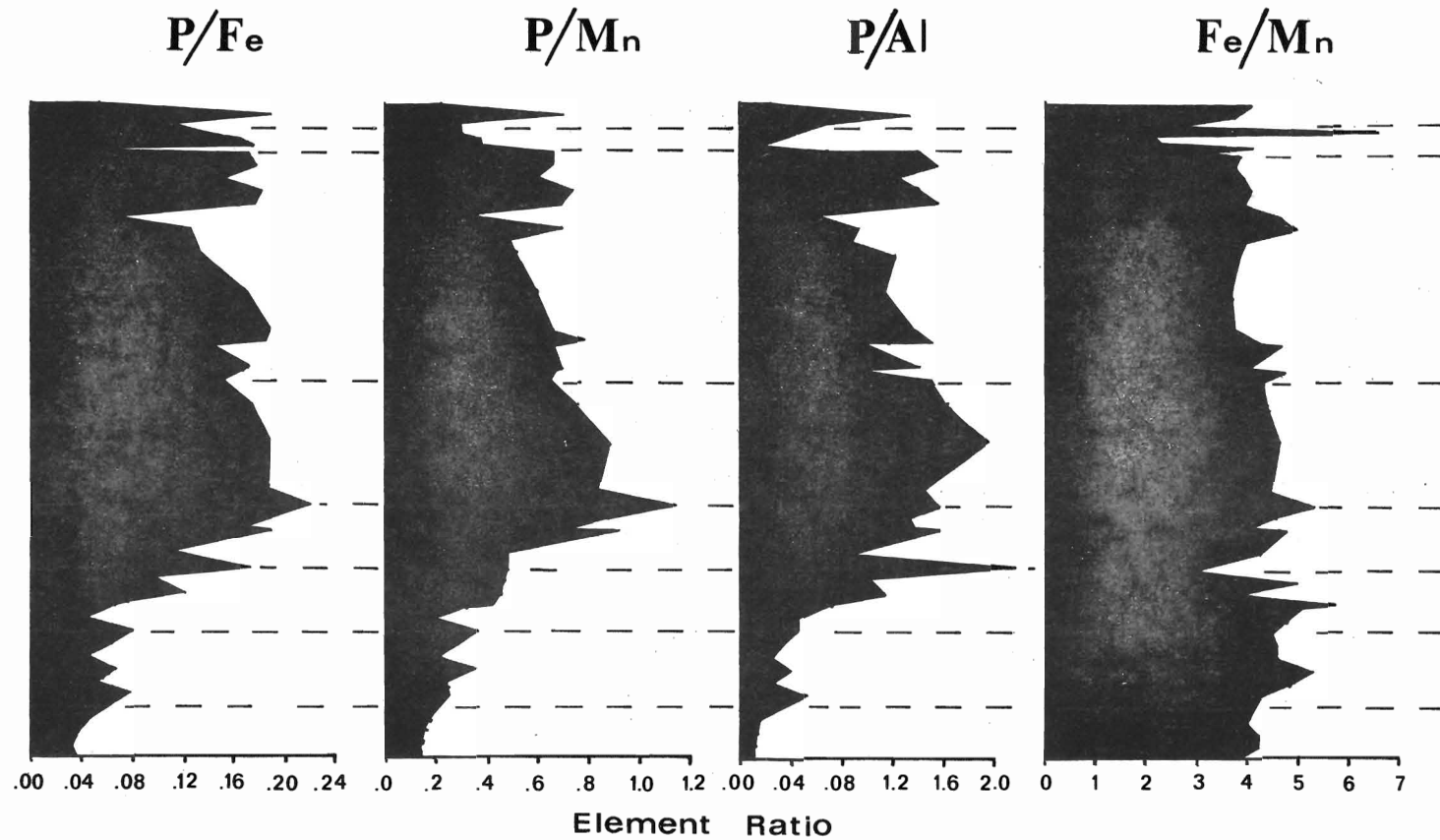
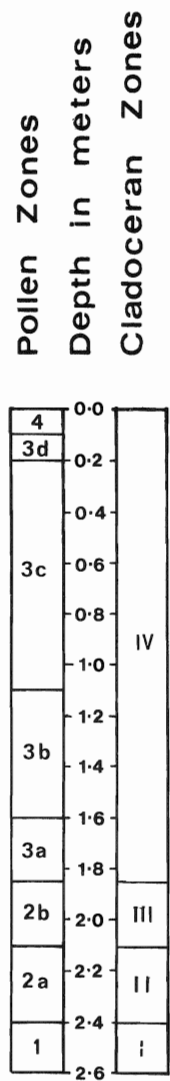
The sediment accumulation rate curves for manganese, potassium, and aluminum (Fig. 6) indicate that the influx of these elements to the lake basin generally followed the pattern described for phosphorus and iron. Postglacial maxima were not recorded however for these three elements during pollen zone 3b and where as phosphorus and iron were low in zone 3d, manganese remained unchanged and potassium and especially aluminum increased (Fig. 6).

Chemical Element Ratios

The phosphorus - to - element ratio curves (Fig. 7) for iron, manganese, and aluminum were similar. Ratios were lowest during pollen zone 1, then increased but were still quite low in zone 2a. In pollen zones 2b and 3a all phosphorus-cation ratios underwent a large increase. Following high mid core values the ratios decreased to a low at the 45 cm level of zone 3c. Values then increased and remained high until the zone 3d/3d boundary. The ratios for Mn and Al remained low in pollen zone 3d. In pollen zone 4 all element ratios increased at the 5 cm level then decreased at the surface (1 cm).

Sediment Fe-to-Mn ratios were derived to estimate redox changes

Figure 7. Phosphorus-to-element ratios for iron, manganese, and aluminum and iron-to-manganese ratios for the Found Lake core.



controlling both the mobilization of elements in the watershed and their precipitation in the lake. Figure 7 indicates the ratio remained relatively constant throughout the core. A significantly lower ratio however occurred at the 1.85 metre level. In the middle of zone 3d the ratio again dropped to a rather low value but then increased to a core maximum at the end of the zone.

Photosynthetic Pigment Analyses

Stratigraphic analyses of photosynthetic pigments were performed as a means of estimating past changes in aquatic primary productivity. Furthermore, it was suggested that variations in the chlorophyll-to-carotenoid ratio can provide insight into the past relative contributions of allochthonous organic matter to the lake (Sanger and Gorham, 1972). Sediment core profiles for chlorophyll and carotenoid derivatives and chlorophyll-to-carotenoid ratios are given in figures 8 and 9. Stratigraphic changes in accumulation rates of photosynthetic pigments were discussed within the framework of Found Lake pollen and paleovegetation zones. Annual sediment accumulation rates of bacteriochlorophyll were determined, however, they are not presented since the values were too low to be measured reliably.

Sedimentary chlorophyll and carotenoid derivative curves (Fig. 8) were similar in outline. Both types of pigments were present in only trace amounts at the onset of the lake's history but increased near the pollen zone 1/2a transition. Pigment accumulation rates underwent a gradual increase from zone 2b to the end of zone 3b (the hemlock minimum). The reestablishment of hemlock as the dominant forest component at the pollen zone 3b/3c boundary marked a dramatic decrease

Figure 8. Accumulation rates of sedimentary chlorophyll and carotenoid degradation products (SCDP) for the Found Lake core expressed as SCDP units deposited per cm^2 of lake bottom per year.

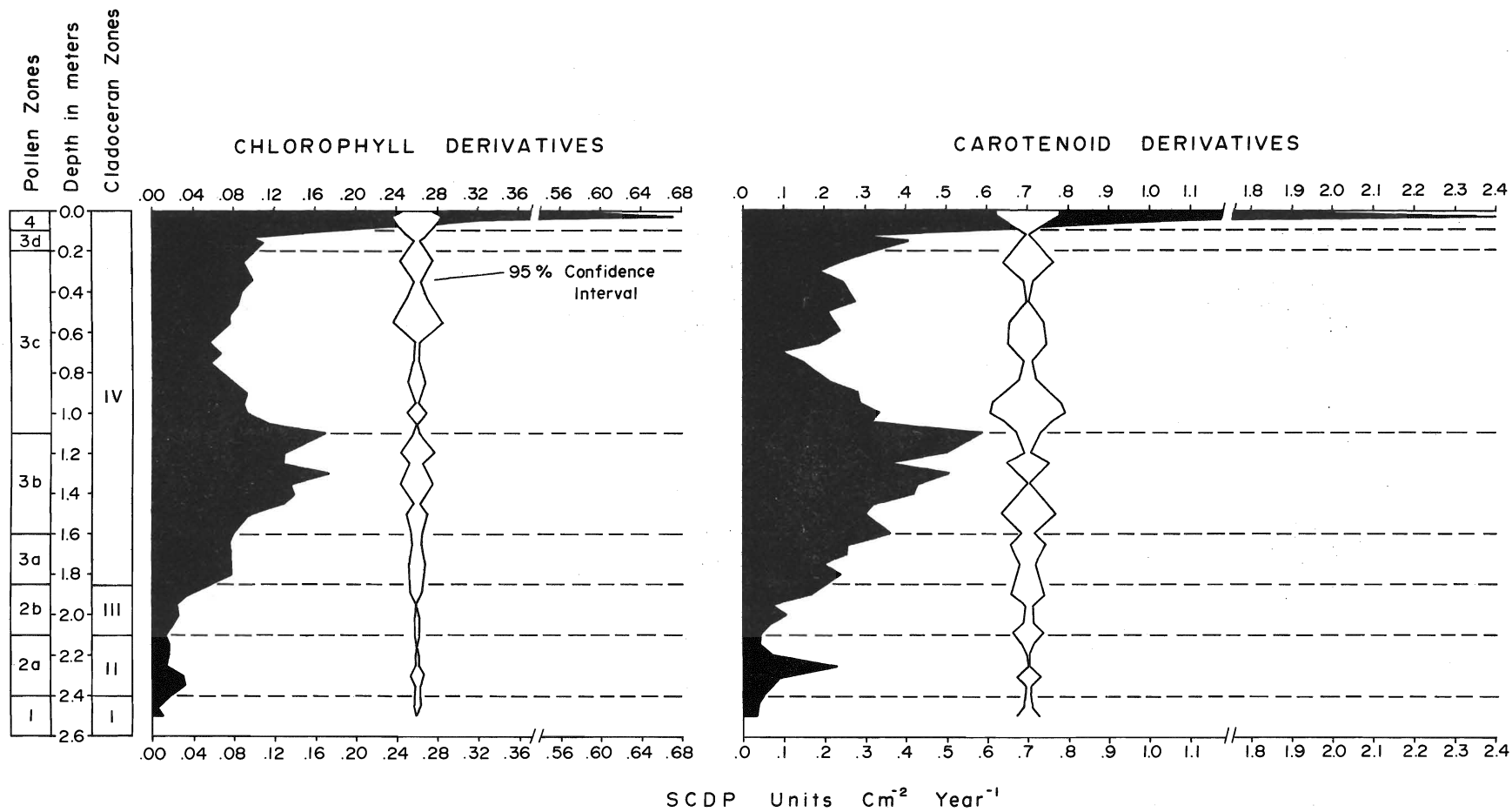
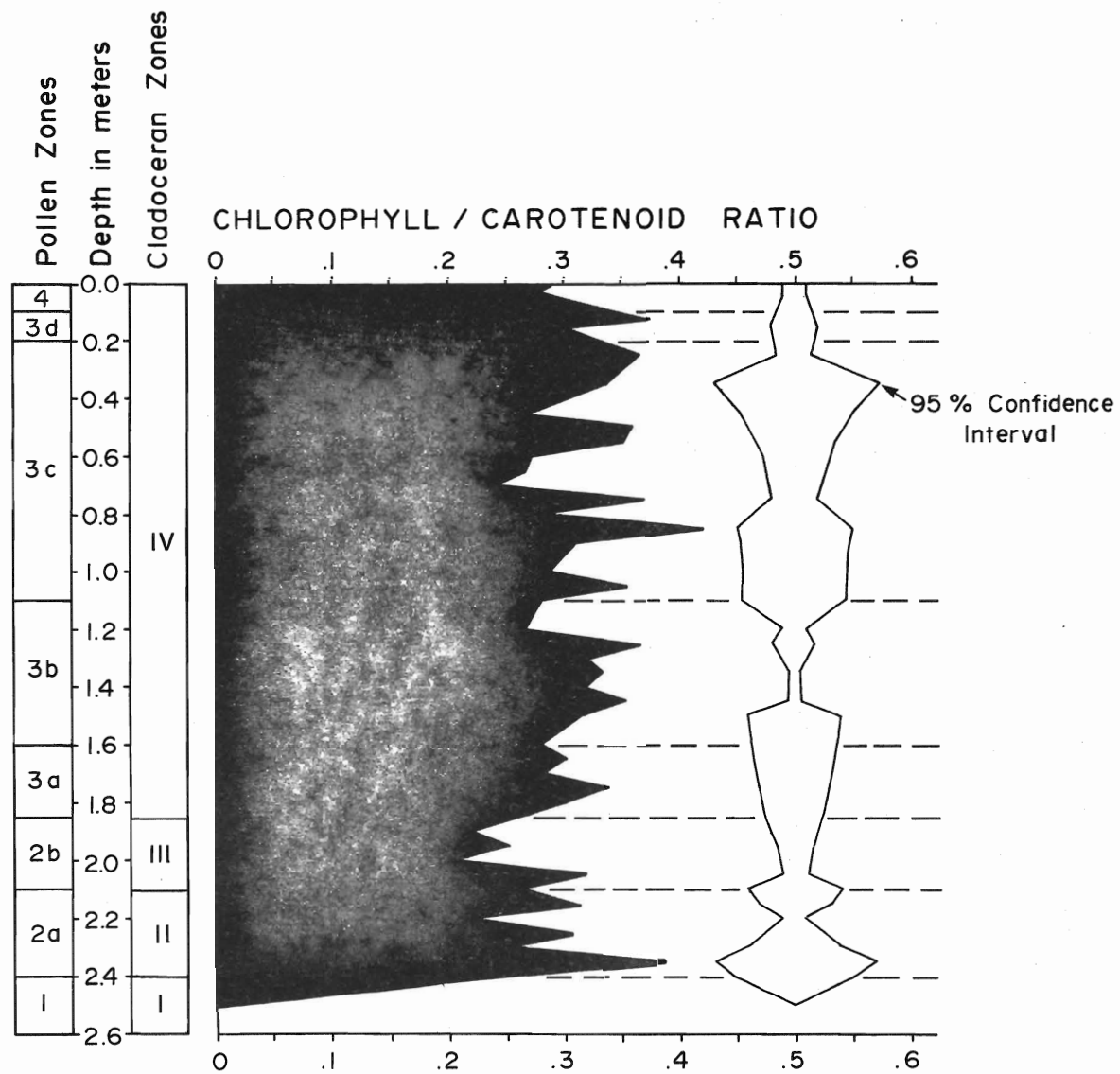


Figure 9. Chlorophyll-to-carotenoid ratios for the Found Lake core.



in sedimentary pigments which continued as a gentler decline to the 70 cm level. The curves then increased slowly until the zone 3d/4 transition where values increased almost exponentially to a core maximum at the 5 cm level (Fig. 8).

Chlorophyll-to-carotenoid ratios were initially (zone 1) extremely low but increased sharply to a peak at the zone 1/2a transition where forested conditions first predominated. Subsequently only minor but still significant changes occurred in the pigment ratio curve.

Algal Microfossil Analyses

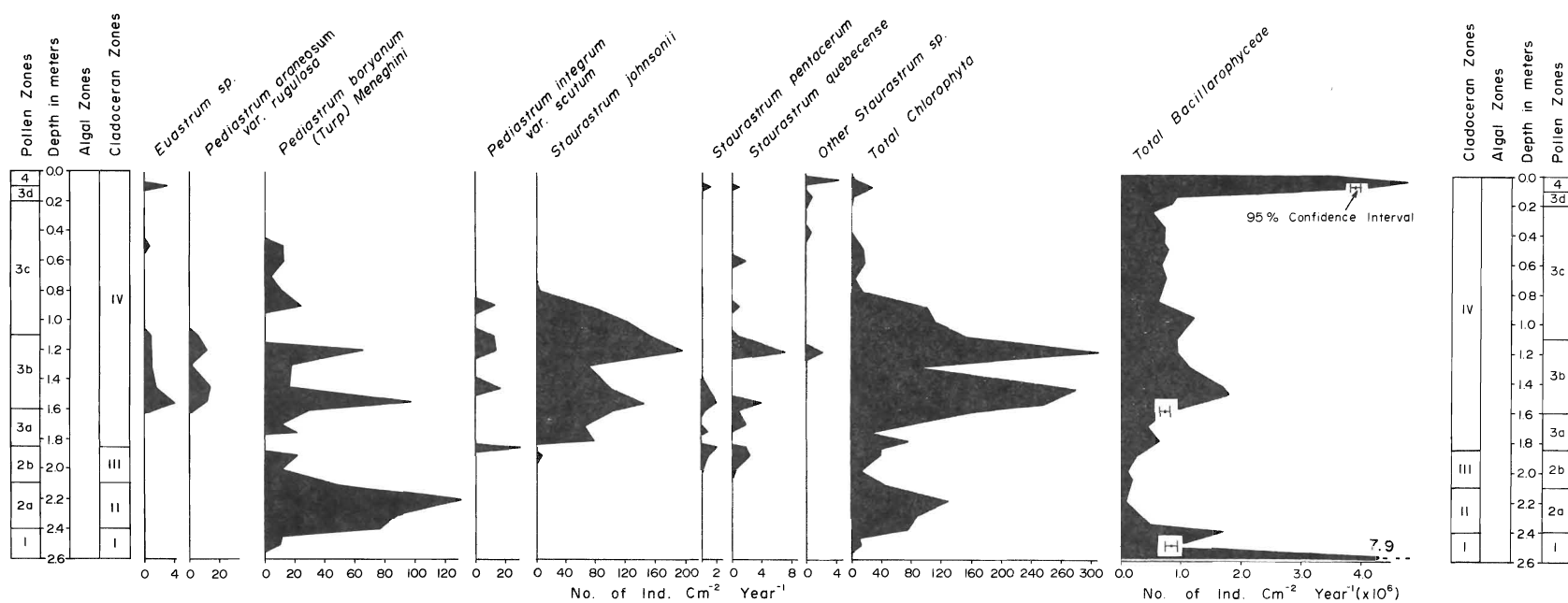
Analyses of stratigraphic changes in the accumulation of diatoms and other algal remains has been utilized as an additional means of estimating past primary productivity levels for Found Lake (Fig. 10). Algal assemblages were dominated by taxa belonging to the Bacillariophyceae, Chlorophyceae, and Dinophyceae. All species counts have been summed and reported as total annual algal accumulation rates (no. of individuals $\text{cm}^{-2} \text{yr}^{-1}$). Estimates of diatom concentrations (no. of individuals/gm dry wt.) were provided by Mr. John Smol.

Diatom accumulation rates although initially quite high following deglaciation increased almost immediately to a small peak at the pollen zone 1/2a transition (Fig. 10). Subsequently values declined and remained low throughout zones 2a and 2b. Zone 3a marked the beginning of a rise which peaked near the stratigraphic middle of zone 3b. Diatom numbers declined shortly after zone 3b and remained low until the later stages of zone 3d. Following this period of relatively constant values a rather sudden and marked rise occurred at the zone 3d/4 transition. Accumulation rates reached a core maximum at the 5 cm level of zone 4

Figure 10. Accumulation rates of selected algal microfossils in the Found Lake core expressed as the number of individuals deposited per cm^2 of lake bottom per year. The diatom analyses were performed by J. Smol.

FOUND LAKE, Peck County, Ontario

ALGAL ACCUMULATION RATE



Bacillariophyceae Analyst: J. Smai
Chlorophyceae Analyst: J.C. Earle

then declined substantially in the uppermost surface centimetre of the sediment core.

The accumulation rate curves for the remaining algal species (Fig. 10) demonstrated their irregular occurrence in the sediments. Several species, such as Euastrum, Pediastrum araneosum var. rugulosa, and Stauroastrum johnsonii were restricted to the middle of the core. High chlorophycean productivity occurred during pollen zone 3b (hemlock minimum) largely due to the abundance of S. johnsonii.

Cladoceran Microfossil Analyses

The fossil remains of cladoceran zooplankton were identified and grouped according to their habitat preferences, i.e. littoral or planktonic. The annual cladoceran accumulation rate curve for the Found Lake core is shown in figure 11. The planktonic cladocera comprised the larger percentage of the total cladocera encountered in the core.

The accumulation rate of planktonic cladoceran forms were low until the middle of zone 2b at which point they increased gradually to a peak at the 1.1 metre level of zone 3b. Then the planktonic cladocera declined suddenly near the zone 3b/3c transition and remained relatively constant until the end of zone 3d. Accumulation rates increased substantially during zone 4 and attained a core maximum at the 1 cm level.

Cladoceran Community Zonation

Cladoceran faunal zones were established to determine periods of Found Lake history characterized by similar cladoceran communities. Spearman's ranked (Fig. 12) and Pearson's product-moment correlation coefficients were used to quantitatively compare the cladoceran

Figure 11. Accumulation rates of planktonic, littoral, and total cladoceran microfossils in the Found Lake core expressed as the number of individuals deposited per cm² per year.

FOUND LAKE, Ontario CLADOCERAN ACCUMULATION RATE

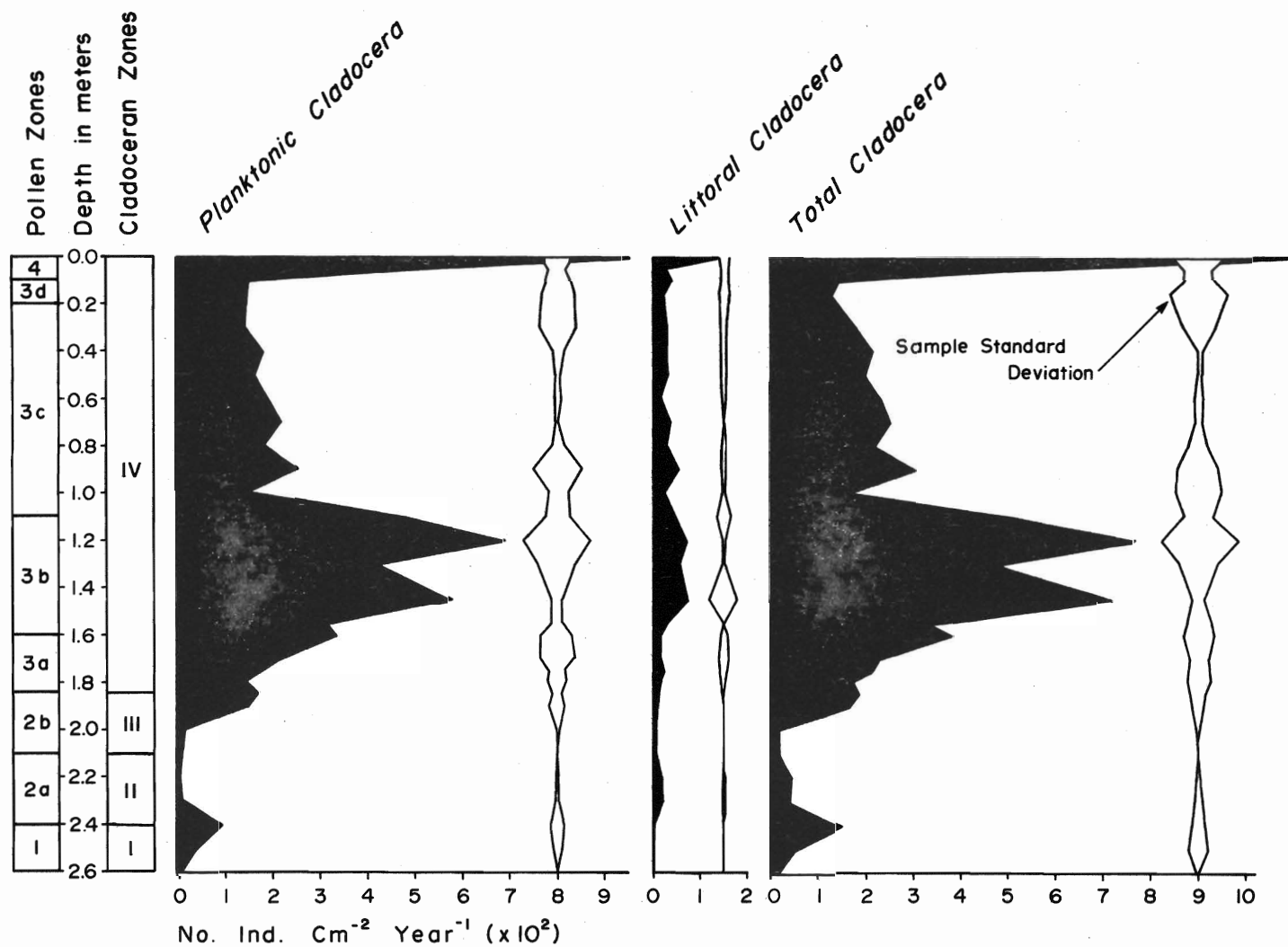
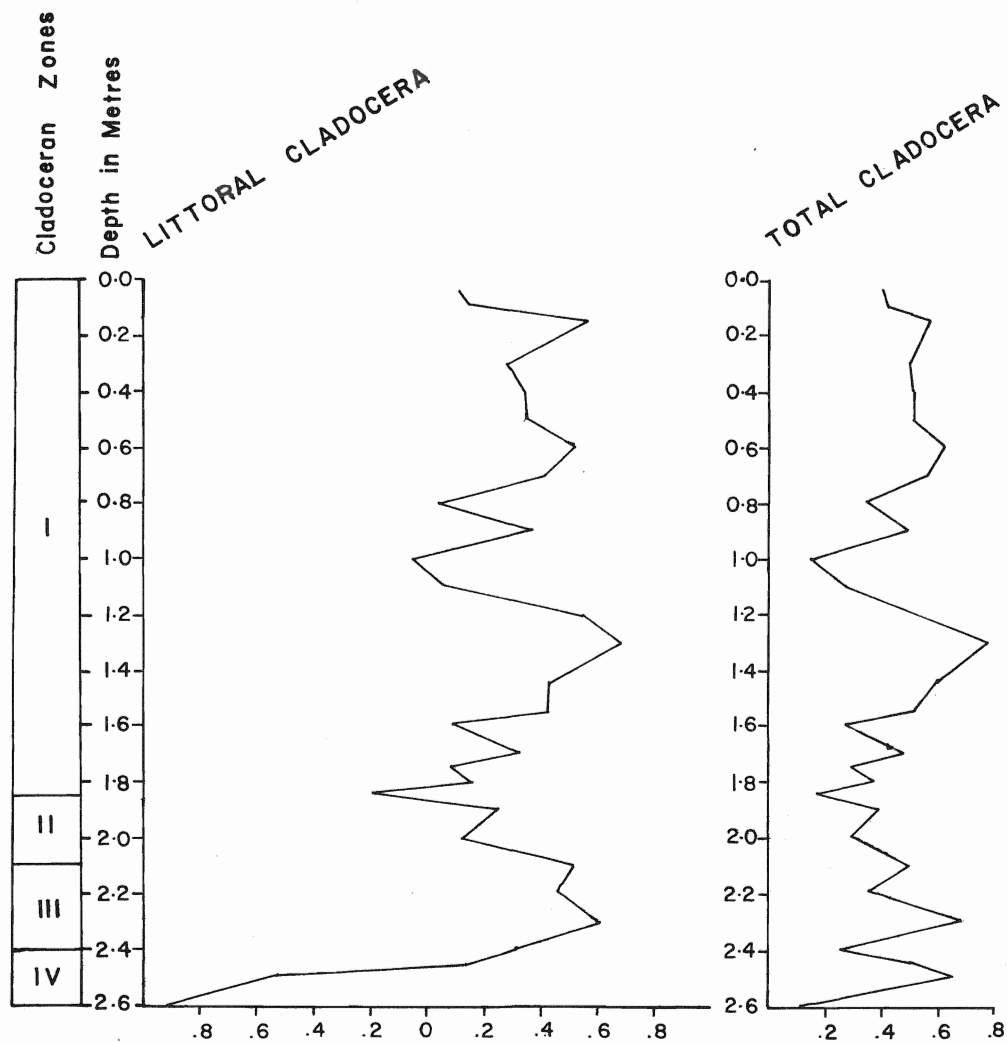


Figure 12. Spearman coefficients of ranked correlation for littoral and total cladocera.



SPEARMAN COEFFICIENTS

communities of adjacent core levels. The author considered that a lower correlation coefficient indicated a greater difference between the cladoceran communities being compared. Core levels with communities substantially different from those found at the next level closer to the surface were designated as zonal boundaries. Therefore the periods of lake history between successive zonal boundaries were characterized by similar cladoceran composition. The results of correlation analyses (Fig. 12) were combined with the more traditional approach of qualitative interpretation to construct four cladoceran zones for Found Lake: Zone I (2.6 - 2.4 metres); Zone II (2.4 - 2.1 metres); Zone III (2.1 - 1.85 metres); and Zone IV (1.85 - 0.0 metres). Figures 13 and 14 show the percentage representation of littoral and planktonic cladoceran species respectively.

Zone I (2.6 - 2.4 metres; ca. 11,800 - 10,600 Y.B.P.)

The littoral species assemblage of zone I was characterized by Chydorus sphaericus, Acroperus harpae, Alonella nana, and Alonella excisa (Fig. 13). In the planktonic community Bosmina coregoni and Daphnia catawba were most abundant (Fig. 14). The cladoceran fauna of zone I was predominantly planktonic as the littoral forms never comprised more than 10 percent of the total cladoceran abundance (Fig. 15).

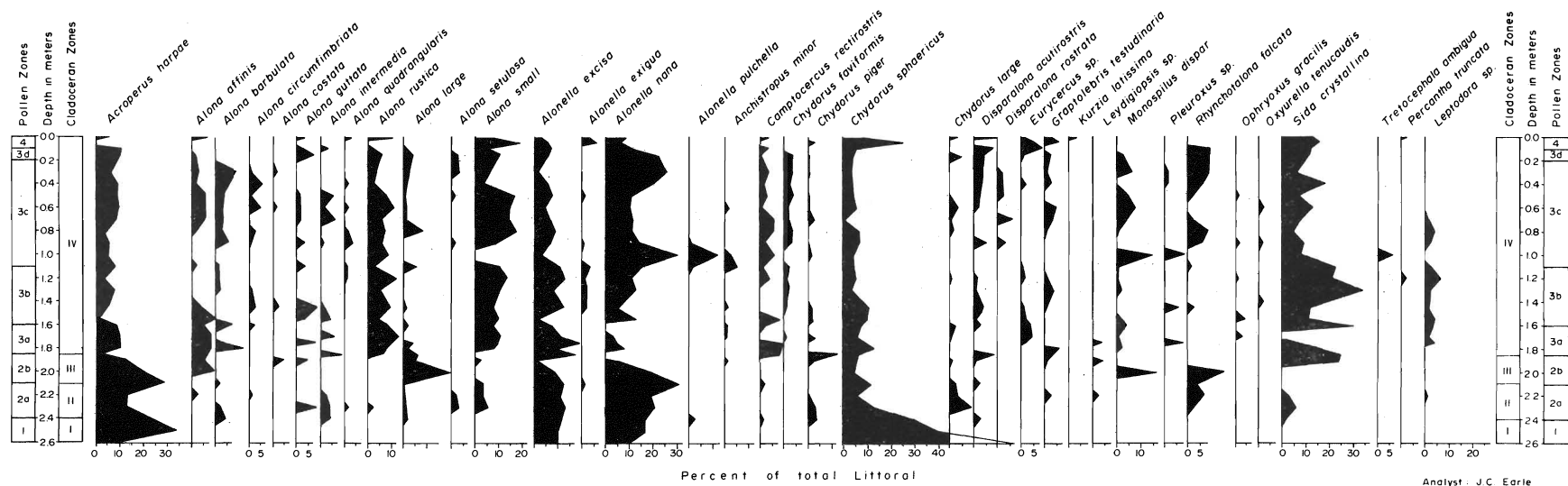
Zone II (2.4 - 2.1 metres; 10,600 - 8,100 Y.B.P.)

Cladoceran zone II can be described as a Daphnia catawba - Alonella nana assemblage zone. Stratigraphically it corresponded to the open pine forest period of pollen zone 2a. The littoral fauna was characterized by Alonella excisa, Acroperus harpae and declining percentages of Chydorus sphaericus. In the plankton of zone II Bosmina

Figure 13. Percent species composition diagram of the Found Lake littoral cladoceran community.

FOUND LAKE, Peck County, Ontario

LITTORAL CLADOCERA



Analyst: J.C. Earle

Figure 14. Percent species composition diagram of the Found Lake planktonic cladoceran community.

FOUND LAKE

PLANKTONIC CLADOCERA

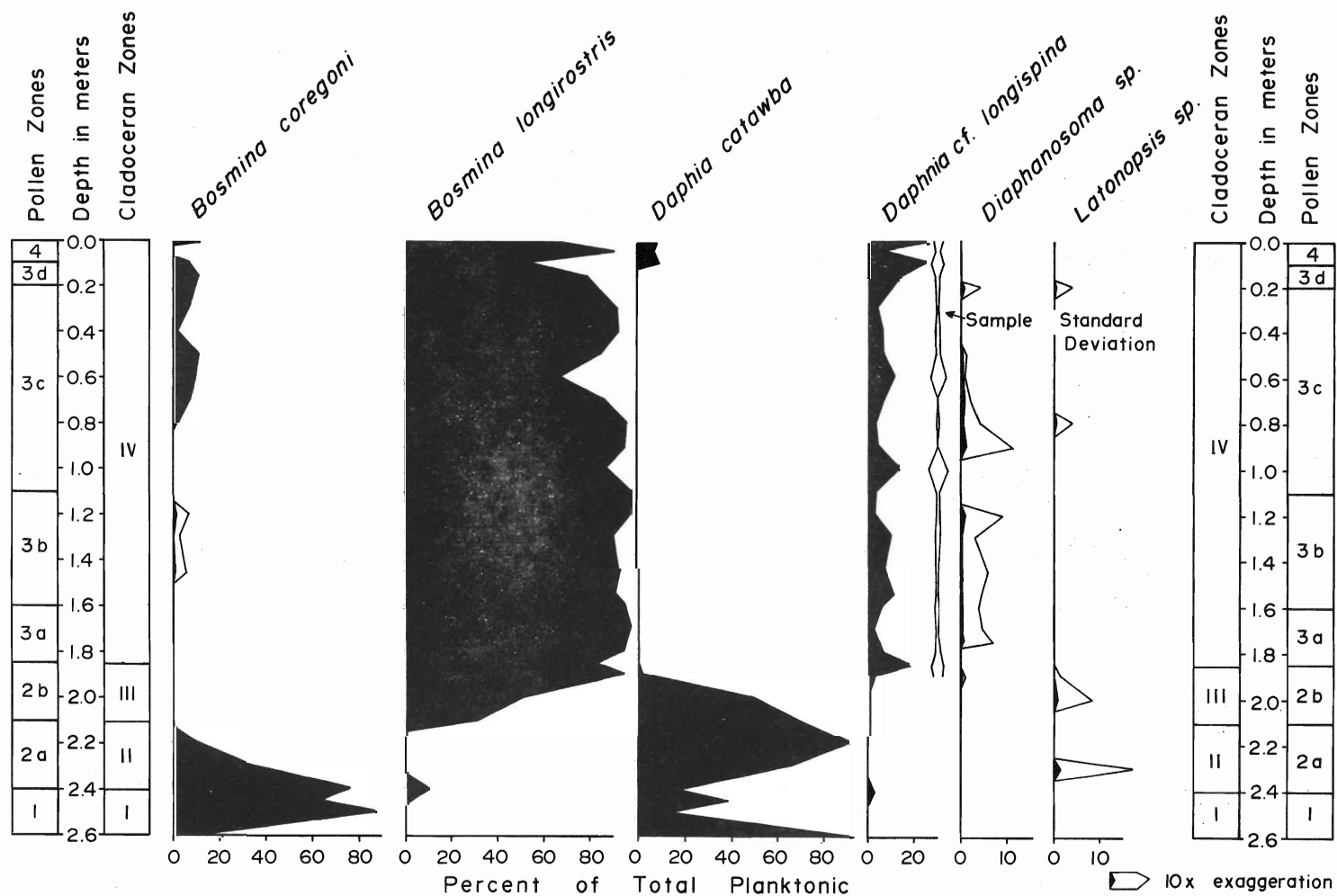
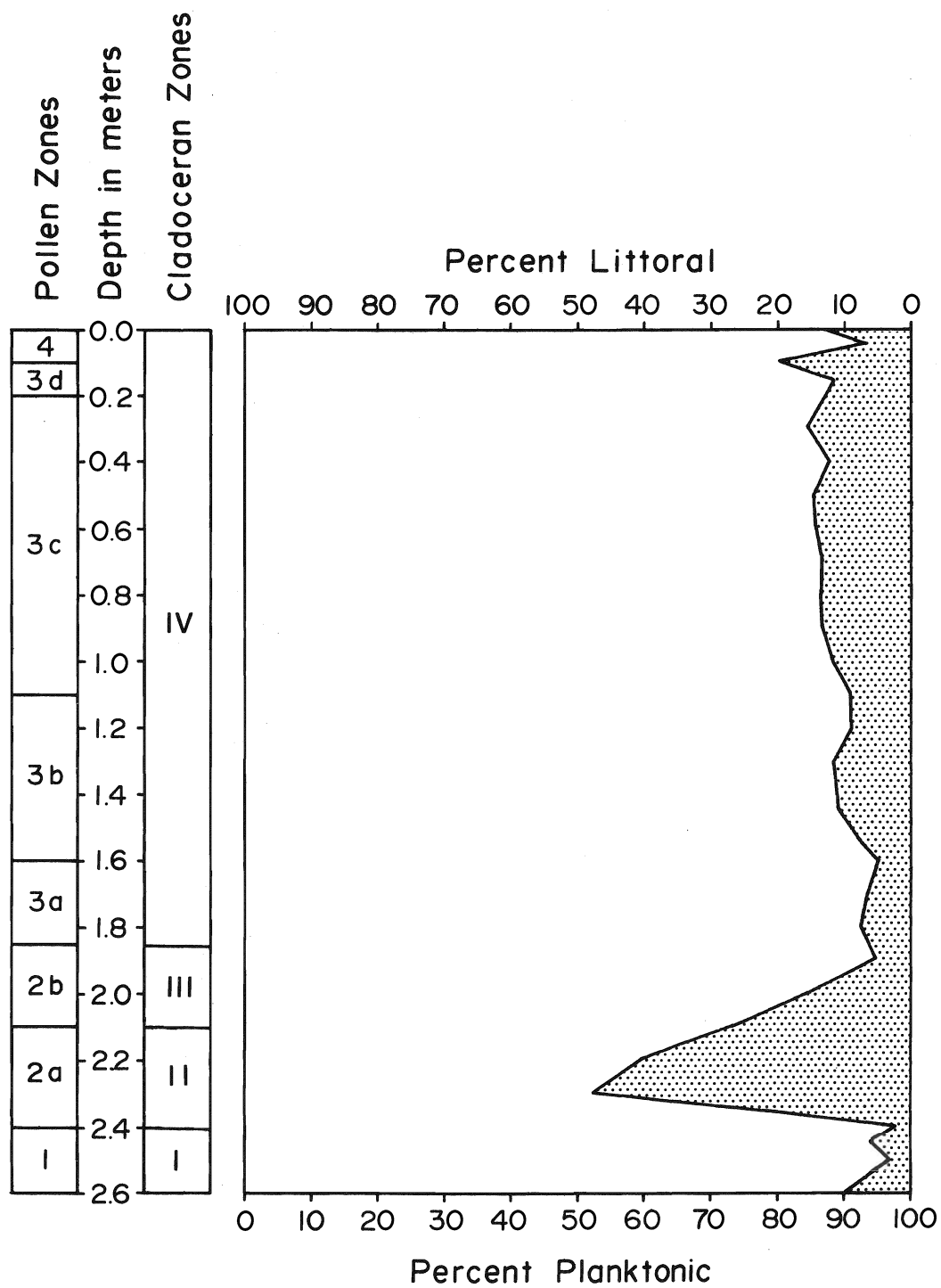


Figure 15. Division of the total cladoceran community into littoral and planktonic components.



coregoni was gradually replaced by Daphnia catawba. The littoral community increased suddenly in the early stages of zone II but had started to decrease again by the later half of the zone.

Zone III (2.1 - 1.85 metres; 8,100 - 5,700 Y.B.P.)

This faunal zone, which corresponds to pollen zone 2b, was characterized by Daphnia catawba, Bosmina longirostris, large Alona and Acroperus harpae. Alonella nana and Alonella excisa dominated the littoral assemblage initially but declined toward the end of the zone when Sida crystallina and Chydorus piger became abundant. In the planktonic component of the cladoceran community Daphnia catawba declined and was eventually replaced by Bosmina longirostris. Representation of the littoral forms continued to decline until the end of zone III when they were again less than 10 percent.

Zone IV (1.85 - 0.0 metres; 5,700 Y.B.P. - present)

This Bosmina longirostris - Sida crystallina assemblage zone extended throughout the entire mixed (deciduous-coniferous) forest period. The littoral community was dominated by Sida crystallina and Alonella nana, while Alonella excisa, Alona rustica, and Chydorus sphaericus were the principal subdominants. In the plankton of zone IV Bosmina longirostris comprised between 50 to 90 percent of the total community.

DISCUSSION

Paleoecological Interpretation of Watershed-Lake Events

Likens and Bormann (1974) and Whitehead and Crisman (1978) suggested that aquatic productivity may be controlled by watershed processes regulating erosion and nutrient release. It is for this reason that the history of watershed-lake events at Found Lake have been discussed within the framework of the constructed paleovegetation (pollen) zones.

Zone 1 (2.6 - 2.4 metres)

The earliest recorded vegetation around Found Lake was tundra-like with scattered stands of black spruce (Picea mariana). Although modern analogues for the pollen spectra of zone 1 are not known, comparison with modern forest-tundra regions in Canada and the USSR suggest that the climate was cold and possibly moist. It is also likely that permafrost conditions prevailed.

Sediment accumulation rates were relatively high following deglaciation but declined quickly as the continental glacier moved progressively north of the area (Fig. 4). The large sediment inputs characteristic of zone 1 were undoubtedly derived from solifluction of unconsolidated glacial material in the watershed. High accumulation rates of aluminum (Fig. 6), a relatively insoluble element, support this view. Organic matter and carbonate data (Fig. 5) indicate the inorganic sedimentation was at a maximum.

~~Chemical input~~ to the lake was high during this period (Fig. 6). However, the major proportion of phosphorus was bound either within

the eroded sediment fraction or with iron, aluminum, or manganese as complex metal hydroxides. Phosphorus was thus largely unavailable for biological growth as reflected in the low phosphorus-to-element ratios (Fig. 7).

Low sedimentary chlorophyll and carotenoid accumulation rates (Fig. 8) and the near absence of chlorophycean algae from zone 1 (Fig. 10) suggests that aquatic primary productivity was quite low. This coupled with the lowest deposition rates of organic matter and total carbonate in the lake's history (Fig. 5) indicate that primary productivity was probably minimal.

Secondary productivity was also low during zone 1 (Fig. 11). Cladoceran numbers may have been limited by either low food availability and/or adverse climatic conditions. In light of the low level of primary production during this period and the nutritional requirements of the cladocera, food availability was probably more important.

Although primary productivity was generally low the diatom community sustained a high level of abundance during this period (Fig. 10). Therefore, aquatic productivity, at least in this sector, may have been higher than was initially interpreted. The dominant diatom however, (Cyclotella stelligera), has a rather small biomass compared to those species found commonly later in the core (Smol, 1979). Hence diatom production during pollen zone 1 was not as high as the accumulation rate curve alone suggests. Neither did the chlorophyll-to-carotenoid ratio indicate that primary productivity was as low as the pigment accumulation rate curves had suggested. Minimal chlorophyll-to-carotenoid ratios (Fig. 9) during zone 1 indicate that a greater proportion of the sedimentary pigments can be attributed to within

lake production.

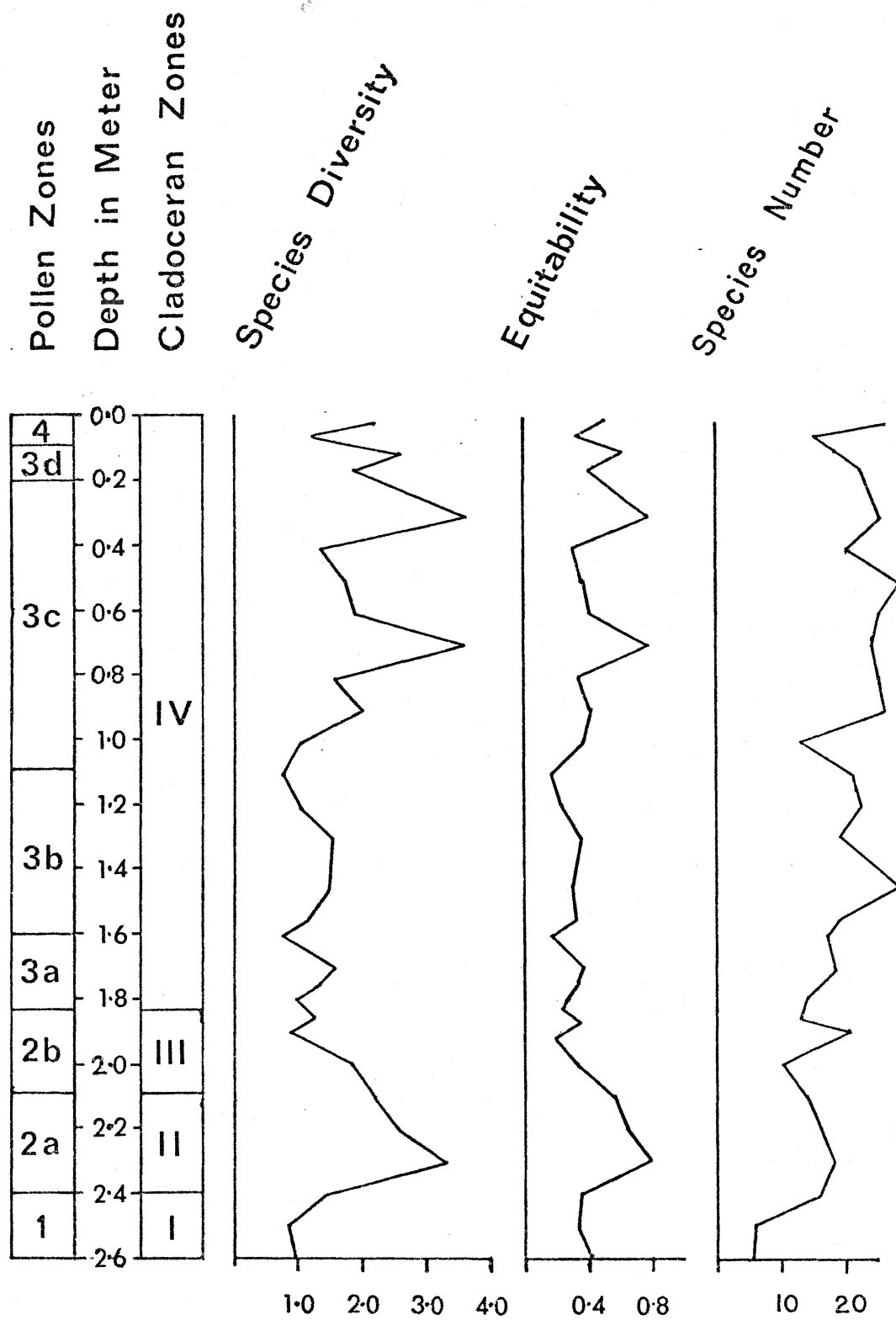
Careful consideration of all the evidence suggests that primary productivity was lower than at any other time during the lake's history. However, enough nutrients were available from the poorly developed soils of the watershed to support fairly abundant populations of littoral diatoms (Smol, 1979).

The planktonic Cladocera of zone 1 comprised over 90 percent of the total cladoceran community. I suggest that aquatic macrophyte growth and thus littoral cladoceran abundance may have been limited by the high turbidity thought to have prevailed at this time.

There is an extensive literature to suggest that species diversity is negatively correlated with productivity (Whiteside and Harmsworth, 1967). Theoretical considerations however suggest that diversity should be low in very young systems (Margalef, 1969). This was confirmed with Found Lake's early cladoceran communities (Fig. 16). Pollen zone 1, although a period of low primary production, also had the lowest cladoceran diversity. Later as productivity increased diversity also increased.

The unproductive nature of Found Lake's waters during pollen zone 1 was suggested by the present ecology of the dominant cladoceran species of the period. The planktonic cladoceran community was dominated by Daphnia catawba and Bosmina coregoni, (Fig. 14) species which are indicative of oligotrophic waters (Harmsworth, 1968). Those species which dominated the littoral community, e.g., Chydorus sphaericus, Alonella nana, and Acroperus harpae (Fig. 13) are also all considered to be typical of nutrient poor lakes (Crisman, 1976).

Figure 16: Total cladoceran species diversity, equitability and species number for the Found Lake core.



Zone 2a (2.4 - 2.1 metres)

A relatively open pine forest gradually replaced the forest-tundra community at about 10,600 Y.B.P. and this condition persisted in the watershed for approximately 2,600 years (Figs. 2 and 3). The forest consisted predominately of red and white pine, birch, and spruce. The climate was warmer and drier than when the forest-tundra vegetation prevailed. Higher chlorophyll-to-carotenoid ratios (Fig. 9) suggest that there was an increase in the proportion of allochthonous organic material being delivered to the lake. However, the sediments remained predominately inorganic (Table 2) and the rate of sediment accumulation was minimal (Fig. 4). The soils and vegetation of the watershed had by this time developed sufficiently to greatly reduce erosion as indicated by the sharp reduction in potassium and aluminum (Fig. 6).

Nutrient input to the lake was generally low during this period as phosphorus accumulation rates were minimal (Fig. 6). However, phosphorus-to-element ratios for iron, manganese, and aluminum increased slightly in zone 2a suggesting that phosphorus had become relatively more available than it had been during the tundra-open forest period (pollen zone 1). The higher nutrient availability of pollen zone 2a may have been due to the large increase in alder trees. Increased alder would have had two interesting effects on nutrient supplies to the lake. Alder is a nitrogen fixer and hence soil nitrate input to the lake would have increased (Lawrence et al., 1967). Also, expansion of alder probably resulted in greater leaf input to the lake system. This would have increased the availability of phosphate and nitrate in the lake, as alder leaves contain high levels of both N and P (Rodin and Bazilevich, 1967) and also decompose rapidly in the aquatic environment (Willoughby, 1974).

Aquatic primary productivity increased only slightly during zone 2a as indicated by increased levels of sedimentary pigments (Fig. 8), organic matter and total carbonate (Fig. 5). Productivity may have been limited by low levels of essential nutrients as phosphorus availability although higher was still relatively low (Fig. 7). Competition with terrestrial vegetation for an already short supply of essential nutrients may also have been important. Nutrient release by terrestrial plants has been shown to be relatively low when the vegetation is actively accumulating biomass (Vitousek and Reiners, 1975). The forests of pollen zone 2a were still relatively open and expanding (McAndrews, unpublished pollen influx data) so that the soils of this period would be expected to lose fewer essential nutrients to ground water than soils associated with mature successional forests.

In at least one case, competition for molybdenum with alder trees has been shown to have limited aquatic productivity (Goldman, 1960). The abundance of alder (Alnus sp.) in the Found lake watershed was maximal during this period (Fig. 2). Molybdenum sequestering by nitrogen fixing alder may have limited the lake's productivity as it did in Castle Lake, California (Goldman, 1961). Since molybdenum is not normally a constituent of granitic rock, molybdenum (Rankama and Sahama, 1949) limiting conditions may have existed.

Lacustrine secondary productivity did not change significantly since the forest-tundra period (Fig. 11). The littoral Cladocera however greatly expanded relative to the planktonic community (Fig. 15). The author believes a reduction in turbidity as demonstrated by a change in the sediment lithology (Table 2) resulted in the increased relative importance of littoral species noted in figure 12. Although littoral

cladoceran abundance did increase slightly the shift to equal proportions of both planktonic and littoral forms was due more to decreased planktonic abundance (Fig. 11). Perhaps planktonic species experienced restrictions on food availability as the result of competition for essential nutrients between littoral zone algae and pelagic phytoplankton. Species diversity and equitability of the total cladoceran community increased (Fig. 16) during pollen zone 2a, possibly as a result of decreased turbidity (increased niche number) and increased immigration of species following climatic amelioration.

The continued dominance of the planktonic assemblages by Daphnia catawba and Bosmina coregoni suggests that the lake was oligotrophic during pollen zone 2a (Fig. 14). The reduced importance of such oligotrophic indicators as Acroperus harpae and Chydorus sphaericus along with the first appearance of several littoral zone species such as Rhynchotalona falcata and large Alona which are typically associated with more nutrient-rich conditions suggests that the lake underwent a very mild enrichment during pollen zone 2a.

Pediastrum boryanum which occurs in a variety of habitats from near mesotrophic to eutrophic conditions but not in the more oligotrophic waters (Whiteside, 1965b) produced a large core maximum during pollen zone 2a. The enrichment may have been due to either an increase in the availability of nutrients or to a climatic amelioration. The continued dominance by Alonella nana and Alonella excisa in the littoral zone coincides with pigment (Figs. 8 and 9) and chemical influx data (Fig. 6) suggesting that the enrichment was only a small one and that the lake still remained strongly oligotrophic.

Zone 2b (2.1 - 1.85 metres)

A dense boreal forest developed and white pine replaced red pine and spruce as the dominant forest components between 8,400 and 6,500 Y.B.P. (Figs. 2 and 3). Floristic changes suggested that the warming and drying trend which began early in zone 2a continued throughout this period. Sedimentation rates remained low until the later stages of zone 2b when they increased along with the density of the boreal forest (Fig. 4). The sediment type changed from a silty gyttja to a more organic-rich algal gyttja (Table 2). Increased litter biomass during this period may have increased the depth of the soil horizon. Since the litter was predominantly coniferous, soil acidity probably increased. The greater acid character of the soil would have enhanced soil reducing conditions and increased nutrient availability (Nihlgard, 1971).

Low element accumulation indicated that nutrient release from the watershed was low during zone 2b (Fig. 6). However phosphorus-to-element ratios were higher than in zone 2a (Fig. 7). This suggests that utilizable phosphorus was relatively more available especially during the later stages of the period when white pine comprised between 80 and 90 percent of the forest. Enhanced soil reducing conditions may have been responsible for the increase. Accumulation rates of phosphorus, iron, and manganese reached small peaks at the end of the zone suggesting that this was a period of higher nutrient release than had occurred earlier in zone 2b. Aluminum influx decreased despite an apparent reduction in soil pH which would serve to enhance aluminum solubility (Dickson, 1978). The decrease in aluminum and potassium at this time was probably due to a decrease in inorganic

sedimentation.

Aquatic primary productivity increased slowly during the boreal forest period and reached a peak at the end of zone 2b. This was indicated by an increase in the level of sedimentary chlorophylls and carotenoids (Fig. 8). -A reduction in chlorophyll-to-carotenoid ratios suggests a greater input from the primary producers of the lake and less input from terrestrial sources. Accumulation rates of both chlorophycean algae and diatoms were low suggesting algal productivity was low. Collectively however, diatoms and the few chlorophycean species which preserve well, comprise such a small proportion of the total autotrophic community of a lake that it is difficult to interpret paleoproductivity from their stratigraphic distribution.

Aquatic secondary productivity was low initially during zone 2b but increased significantly a short time later (Fig. 11). This increased productivity was inferred from the increase in the planktonic component of the cladoceran community (Figs. 11 and 15). Concurrently, littoral zone cladoceran species' representation declined (Fig. 15).

Zone 2b marked the complete replacement of Daphnia catawba by Bosmina longirostris (Fig. 14). The sudden rise of B. longirostris to represent over 90 percent of the total planktonic community coincided with declines in species diversity and equitability (Fig. 12).

Bosmina longirostris is known to occur in the plankton of more nutrient-rich, productive waters than are either B. coregoni or Daphnia catawba (Bawkiewicz 1934; Deevey 1942; and Brooks 1969). The replacement of D. catawba, B. longirostris having already been replaced, suggests that Found Lake became increasingly productive during pollen zone 2b. Further, during this period the last of the dominant early

lake period "oligotrophs", Acroperus harpae and Alonella nana, declined substantially.

The replacement of planktonic "oligotrophs" by species found in more productive waters has been observed in several lakes. Frey (1955) first reported a stratigraphic replacement of B. coregoni by B. longirostris at Langsee, Austria. Goulden (1964) at Esthwaite Water, and Harmsworth (1968) at Blelham Tarn, England, were able to correlate the replacement of B. coregoni by B. longirostris with the establishment of a Chironomus midge community, indicating a pronounced increase in the lake's productivity. The replacement in Found Lake was unique in that B. longirostris never replaced B. coregoni directly. Instead Daphnia catawba replaced B. coregoni first over a period of 2,600 years after which D. catawba was replaced by B. longirostris. This last change took place gradually over a period of 2,000 years.

Zone 3a (1.85 - 1.60 metres)

The dense boreal forest of pollen zone 2b was replaced by a hemlock dominated mixed deciduous-coniferous forest early in zone 3a. Beech, maple and hemlock became increasingly important (Fig. 3) indicating that the climate had probably become warmer and moister than it had been during the boreal forest period (Potzer 1953; Mott and Farley-Gill 1978). Sediment accumulated in the lake basin at a faster rate during this period (Fig. 4) probably due to an increase in surface runoff and an increase in the amount of litter associated with the development of a mixed forest. Watershed chemical release (Fig. 6) and phosphorus availability (Fig. 7) also appeared to increase as the vegetation became more dominated by deciduous taxa.

Rodin and Bazilvich (1967) demonstrated major differences in the

nutrient dynamics of coniferous, deciduous, and mixed forests. They compiled data from several authors to show that deciduous leaves generally have a greater concentration of nutrients than conifer needles. Deciduous leaves also decompose more quickly under similar environmental conditions such that nutrient recycling times are considerably shorter (Williams and Gray, 1974). Furthermore, deciduous forests were generally found to produce greater annual amounts of litter (Rodin and Bazilvich, 1967). Consequently, it would appear that deciduous litter generally provides a greater amount of nutrients for lakes than does coniferous litter.

Temperature and soil pH conditions also affect nutrient dynamics (Williams and Gray, 1974). Soil temperatures were undoubtedly higher during pollen zone 3a than during the boreal forest period. This would have increased the rate of decomposition. The shift to greater deciduous content would also result in less acid litter which in turn, would increase the solubilization (and output) of cations. A decrease in cation (Fe, Mn, and Al) flushing to the lake would result in reduced phosphate complexing with these ions (Mackereth, 1966).

The heavier rainfall of the period probably served to increase the amount of nutrients washed from the crowns of trees. Rodin and Bazilvich (1967) showed that this amount can be substantial especially in deciduous forests where the larger surface area of the leaves facilitates nutrient removal by washing. The net result of the combined effects of changes in vegetation type, temperature, precipitation and soil pH conditions was to increase watershed nutrient release to the lake.

Levels of sedimentary chlorophylls and carotenoids indicate that

aquatic primary productivity increased at the same time that nutrient availability increased (Fig. 8). The magnitude of the productivity increase may be exaggerated however, as chlorophyll-to-carotenoid ratios suggested that allochthonous contributions to the pigment complement had also increased since pollen zone 2b. Data on diatoms (Fig. 10), sediment organic matter (Fig. 5), and total carbonate (Fig. 5) further support the suggestion that primary productivity was higher during this period than during any prior period. Furthermore, aquatic secondary productivity also increased significantly during zone 3a (Fig. 11).

Planktonic representation in the cladoceran community reached its highest level since pollen zone 1 (Fig. 15). Qualitatively, the plankton of zone 3a changed substantially (Fig. 14). Bosmina longirostris dominated the community while Daphnia c.f. longispina and Diaphanosoma, which were rare below 1.85 metres, increased markedly in zone 3a. Crisman (1976) felt Diaphanosoma and B. longirostris characterized a period of high productivity in North Pond, Massachusetts.

Zone 3b (1.6 to 1.1 metres)

Hemlock, the dominant tree species in zone 3a declined rapidly after the 3a/3b transition and remained poorly represented throughout zone 3b (Figs. 2 and 3). Hemlock was first replaced by white pine and shortly afterwards by maple, birch and beech. These changes in the dominant vegetation type may indicate that the climate had become warmer and drier than it had been since the last interglacial (Mott and Farley-Gill, 1978).

Alternatively, Davis (1977) has suggested that the decline was due to a pathogen on hemlock and not a result of climatic change. She

proposed this because of the suddenness and synchronization of the "hemlock decline" over most of eastern North America at 4800 Y.B.P.

The case for the widespread outbreak of a pathogen however is highly speculative and far from convincing. Evidence for a "climatic optimum" in North America, on the other hand, has been abundant (Schwarzbach 1963; Bryson and Wendland 1967). Comparison of the modern pollen rain and climate with paleovegetation indicates that a "hypsothermal of 2°C above modern temperatures had occurred in central and northern Ontario at about 5000 Y.B.P. (McAndrews, 1979). Prairie invasion in northwestern Ontario suggested that substantially drier soils occurred during this period. However, McAndrews (1979) found no evidence of a climatic amelioration in south-central Ontario. Hemlock was however disregarded as a climatic indicator because its numbers were believed to have been controlled by a pathogen.

Davis^{*} (1977) biological explanation for the marked reduction in hemlock trees has been based almost entirely on the apparent suddenness and synchronicity of the decline over the geographic range of hemlock. It was suggested that 4,800 years ago hemlock populations all over eastern North America declined within about 60 years to at least one tenth their previous size (Davis, 1977). Vegetational adjustments are expected to respond more slowly to climatic change than this. A personal search of the palynological literature however has revealed many areas in which the "hemlock decline" was neither as sudden nor as synchronous as had been suggested. The decline at Belmont Bog, New York, took approximately 600 years (Spear and Miller, 1976) while the decline took about 530 and 315 years respectively at Van Nostrand Lake (McAndrews, 1973) and Edward Lake (McAndrews, unpublished). Furthermore, radio-

carbon dating has estimated the "hemlock decline" started 4,800 Y.B.P. at Found Lake, 5,800 Y.B.P. at Van Nostrand Lake and 6000 Y.B.P. at Second Lake (McAndrews, unpublished). It seems then that within the geographic region of southern Ontario the start of the "hemlock decline" varied by as much as 1,600 years.

The pollen record has indicated a number of fairly rapid declines in tree species just as sudden as the "hemlock decline". The substantially reduced percentages of spruce and pine, apparently caused by climatic changes in the early Holocene are two examples. In Lake Ontario spruce percentages fell 20 fold within 50 to 100 years (McAndrews, 1972). Spruce pollen also declined from nearly 90 percent to about 5 percent in less than 100 years at Van Nostrand Lake (McAndrews, 1973). Rapid declines in pine percentages have been found at several sites including Barry Lake and Edward Lake (McAndrews, unpublished). Furthermore, virtually instantaneous falls in pollen percentages have been recorded for poplar (Populus) and tamarack (Larix) at a number of sites (e.g., Rodgers Lake, Davis 1969; Basswood Road Lake, Mott 1975).

The major arguments for the "hemlock decline" having been caused by a pathogen appear to be highly questionable. Therefore, in the absence of evidence to the contrary and since climatic amelioration has been well documented elsewhere (Bryson and Wendland, 1967) I believe the decline can best be attributed to a substantial warming and drying of the climate. Increased occurrence of forest fires may have been responsible for the suddenness of the decline at some locations especially where droughty conditions prevailed. However, the author feels that climatic change is sufficient to explain the fairly sudden vegetational

responses observed at many sites.

Several people believe a biologically controlled event, probably a pathogen specific to hemlock, provides the most plausible explanation for the "hemlock decline". Whether this proves to be true or not, alternative explanations should be taken seriously. Climatic variation should not be called upon routinely to explain paleovegetational changes.

Element accumulation rates indicate that the "hemlock minimum" was a period of increased nutrient release (Fig. 6). The high P-to-cation ratios for iron, manganese, and aluminum suggest that the phosphorus deposited during this period was associated with organic material. In order for phosphorus to have been incorporated into the organic fraction of the sediment it must have been assimilated by plants. I believe the phosphorus was largely associated with autochthonous production. Alternatively, a considerable amount of phosphorus may have been incorporated within the terrestrial fraction of the organic matter. However, phosphorus is released rapidly from decaying plants, usually before it has had an opportunity to be transported to the lake (Keup, 1968). Therefore, the high phosphorus-to-cation ratios recorded for pollen zone 3b probably suggest there was an increase in the supply of soluble phosphate since this is the only primary form be assimilated by aquatic autotrophs.

The increased release and availability of nutrients during this period was probably the result of 5 major factors: 1) increased litter biomass associated with greater deciduous tree content, 2) increased rates of decomposition associated with elevated soil temperatures and greater soil aeration, 3) decreased cation flushing

possibly allowing phosphate released to the lake to be assimilated by autotrophic organisms, 4) increased time for phosphorus reduction and dissolution associated with reduced leaching and higher soil pH, and 5) runoff sufficiently intense to remove much of the accumulated litter associated with the relatively quick spring melts characteristic of deciduous forest (Reiners, in Whitehead et al., 1973).

Increases in sediment organic matter and carbonate (Fig. 5), algal microfossils (Fig. 10), and sedimentary pigments (Fig. 8) suggest that aquatic primary productivity increased during this period probably as a result of increased availability of phosphorus. The lake's productivity appeared to have been highest during the latter half of the "hemlock minimum" when the forest was predominantly deciduous in composition.

The restricted distribution of the alga Pediastrum araneosum var. rugulosa to pollen zone 3b supports the suggestion that this was a period of high algal productivity. Florin (1957) found P. araneosum abundant in only three lakes, all of which were eutrophic. In a core from Kirkkonummi Lake, southern Finland, P. araneosum showed its greatest relative abundance during the eutrophic phase of the lake's history (Alhonen and Ristiluoma, 1973). Furthermore, the planktonic cladoceran community of zone 3b remained dominated by Bosmina longirostris (Fig. 4), an indicator of relatively productive waters.

Aquatic secondary productivity, like primary productivity, was generally high during the "hemlock minimum" and reached its highest level late in the zone (Fig. 11). However, secondary productivity did not peak at the same levels as primary productivity. Just the opposite occurred. Several explanations may account for this.

Increases in autotrophic production may have involved blue-green algae which are not grazed as readily as other algal taxa (Sorokin et al., 1965). This being the case, cladoceran food availability would have been effectively reduced. Alternatively, increased predation may have outweighed increased food availability ~~as a~~ final population determinant. The latter hypothesis is partially supported by the distribution of Leptodora in the Found Lake core. This species which preys on small cladoceran species was restricted mainly to pollen zone 3b (Fig. 13).

The planktonic component of the cladoceran community of zone 3b remained dominated by Bosmina longirostris (Fig. 14). The species presently occurs in mildly enriched oligotrophic to extremely eutrophic lakes and is considered an indicator of productive waters (Harmsworth, 1968).

Zone 3c (1.1 - 0.2 metres)

This zone records the reestablishment of hemlock as an important forest component associated with decreasing pine and increasing beech and spruce. The return of hemlock as the dominant tree species suggests a moister climate than existed during the "hemlock minimum". The continued importance of several mesophytic taxa such as maple, beech, and elm suggests that the mean annual temperature did not change appreciably.

The release of phosphorus and iron from the watershed decreased at the start of pollen zone 3c (Fig. 6) only to increase again toward the end of that zone. Levels of phosphorus and iron however never returned to those levels reached during the "hemlock minimum". The other elements analysed remained unchanged throughout zone 3c.

Phosphorous-metal ion curves (Fig. 7) suggest there was probably a gradual decline in the supply of phosphate to the biota of the lake throughout the greater part of zone 3c. Phosphorus availability then appears to have increased again during the last 20 cm of the zone.

Pigment and diatom accumulation rates decreased after the zone 3b/3c transition (Figs. 8 and 10) suggesting that aquatic primary productivity had declined in zone 3c. This early trend appears to have reversed itself during the latter half of zone 3c. Data on cladoceran accumulation rates (Fig. 11) indicate that Found Lake secondary productivity decreased sharply and remained low throughout this period. Pediastrum araneosum, an indicator of eutrophic conditions, disappeared abruptly at the boundary between zone 3b and 3c. This supports the claim that zone 3c was a period of reduced primary productivity. Possibly the reason behind the decline in lacustrine productivity during zone 3c has to do with the renewed importance of hemlock as a dominant terrestrial component. Reduced litter biomass associated with greater coniferous content in the forest probably brought about a decrease in the quantity of nutrients released from the watershed. Increased cation flushing associated with higher soil acidity may have immobilized phosphate in the lake system but it is questionable whether soil pH dropped sufficiently in zone 3c to have had an appreciable influence. The trend toward slightly higher productivity in the last half of this period corresponds closely to the decline in white pine and subsequent increased importance of maple and beech.

Zone 3d (0.2 to 0.1 metres)

The climate changed abruptly approximately 450 years ago becoming cooler and moister. In Europe where climatic parameters were being

monitored during this period, records show that the mean annual temperature was lower and the precipitation was higher than today (Schwarzbach, 1963). The initiation of mesic succession in the North American Midwest at about 1550 A.D. reflected this trend toward cooler and moister conditions (Bryson and Wendland, 1967). In the Found Lake region, spruce, fir, and hemlock increased in abundance while many of the more mesophytic hardwoods such as maple and beech declined. The increased importance of hemlock is generally thought to indicate a moister environment (Mott and Farley-Gill, 1978).

The release of phosphorus and iron from the watershed may have decreased as the result of a reduced litter fall in a more coniferous dominated forest. Reduced availability of phosphorus (Fig. 7) occurred possibly as the result of increased precipitation with iron, manganese, and aluminum. Increased leaching and moister, less aerated soil would also have served to retard phosphorus availability by reducing the overall reduction of insoluble forms of phosphorus (e.g., ferric phosphate \rightarrow ferrous phosphate). The increased precipitation and soil acidity characteristic of this period would have enhanced the rate of leaching. An increase in aluminum suggests substantial erosion of soil, bedrock, and glacial material had occurred, probably as a result of increased precipitation and a change in the pattern of spring runoff. Soil pH could not have decreased sufficiently to appreciably affect aluminum mobilization at this time as the solubility of Al is low above pH 5.5 (Dickson, 1978).

Sedimentary pigments (Fig. 8) and total sedimentary carbonate (Fig. 5) increased slightly during this period suggesting that aquatic primary productivity may have increased or at least remained

unchanged at a time when soluble phosphorus appears to have been less available (Fig. 7). However, chlorophyll-to-carotenoid ratios provide no indication that the increased pigment accumulation rates of the period were not the result of increased allochthonous production. Furthermore, the composition of the planktonic and littoral cladoceran communities provided no evidence to support a suggestion of increased productivity during this zone. In fact, Bosmina longirostris, an indicator of enriched conditions, decreased to a postglacial low (Fig. 14). Total cladoceran accumulation rates indicate that aquatic secondary productivity decreased during pollen zone 3d (Fig. 11).

Zone 4 (0.1 to 0.0 metres)

This period marks the beginning of man's modification of the region around Found Lake. The start of forest clearance is recorded in the stratigraphic record by a sudden increase in the percentage of Ambrosia and herbaceous pollen (Fig. 2). Based on historical records of lumbering and farming activities in southern Ontario I have suggested a date of approximately 100 Y.B.P. for the Ambrosia horizon. This date is probably a conservative one as Terasmae (personal communications) has suggested a date of about 1860. Core minima for white pine in zone 4 reflects the selective cutting of this species both within Algonquin Park and southern Ontario.

The increased importance of maple in the forests of the last 100 years reflects either an amelioration of the climate or a replacement of those trees cut in lumbering operations. Other than the increased importance of sugar maple the vegetation of pollen zone 4 failed to indicate any warming trend. Instead the climate for eastern North America appears to have remained cool and moist (Davis et al.,

1975; Mott & Farley-Gill, 1978).

Forest clearance and activities related to the construction of highway 60 between 1932 and 1934 caused a large increase in the rate of sediment influx to the lake (Fig. 4). A large workmen's camp located less than 100 metres from the lake (Ministry of Natural Resources, 1978) was probably the main source of material. Chemical release from the watershed and incorporation into the sediments of the lake increased almost exponentially (Fig. 6) at this time. Phosphorus availability remained low at the beginning of zone 4 as vegetative clearance had probably not yet begun in this watershed (Fig. 7). Phosphorus-to-element ratios for Fe, Mn, and Al suggest that soluble phosphate may have increased immediately following the construction phase. However, much of this phosphorus was probably bound within terrestrial plant material and as such would not have been readily available for growth.

Secondary productivity unlike primary productivity, was low until about 1932 when construction of the road started. All the evidence so far examined including that from diatoms (Smol, 1979) suggests that this occurred at the 5 cm level of the core. In the planktonic cladoceran community the disappearance of Bosmina coregoni provides further evidence that this level represented a period of relatively higher lake productivity. Many littoral zone species associated with oligotrophic conditions such as Acroperus harpae, Alona affinis, and Alona rustica also disappeared while Chydorus sphaericus and Alonella exigua reached postglacial peaks. Chydorus sphaericus is known to utilize filamentous blue-green algae as a substrate (St. Mikulski, 1978). Under enriched conditions blue-

green algae often dominate so that high percentages of C. sphaericus are often associated with the eutrophication of a lake (Goulden 1964 and 1966; Alhonen 1970). The increased abundance of C. sphaericus at the 5 cm level of zone 4 supports the suggested increase in productivity at this point.

Presently the blue green alga Gleotrichia echinulata dominates the late summer plankton of Found Lake indicating that the alkalinity of the lake may have increased following road construction (Dickman, personal communications). G. echinulata, like Aphanizomenon flos-aqua and Microcystis aeruginosa, often forms a dense suspension of thalli in upper lake levels (Prescott, 1962). This would have provided a suitable substrate for C. sphaericus. Hutchinson (1967) stated that Gleotrichia species often form water blooms in the more productive lakes. In Found Lake I believe the appearance of G. echinulata indicates a relative enrichment of the lake in recent years.

The distribution of Chydorus sphaericus in sediment cores is rather puzzling since it appears to occur abundantly under two greatly different types of lake environments. Their pelagic association with blue-green algal blooms in enriched lakes has been mentioned. The species is also found in great abundance shortly after glacial retreat. In the "early" lake, C. sphaericus inhabits the littoral zone macrophyte beds. To date limnologists believe the taxa has a rather wide range of ecological tolerances which permit it to inhabit both nutrient rich and nutrient poor waters. Recently this year Frey (personal communications) has provided evidence that demonstrates the occurrence of two separate populations (species) of C. sphaericus in lake Itasca, Minnesota. In light of this it is reasonable to suggest

that the species of C. sphaericus which dominated in pollen zone 1 may have been different from the species found abundant during pollen zone 4. It is most likely however, that except for pollen zone 1, both species of C. sphaericus were present in various proportions throughout the entire history of the lake.

Cladoceran Productivity and Community Structure

Successional changes in cladoceran communities as a reflection of variation in aquatic productivity have long interested limnologists. The most documented has been the replacement of Bosmina coregoni by Bosmina longirostris concurrent with increasing lake productivity (e.g., Deevey 1942; Goulden 1964; Harmsworth 1968). Often Daphnia carawba was reduced in importance (e.g., Crisman, 1976) or replaced by Daphnia cf. longispina as had occurred in this study. Although it has been generally agreed that both changes are an indication of increasing productivity, the cause of these changes has not yet been established.

The effect of size selective predation on zooplankton populations has been well documented (Brooks and Dodson 1965; Brooks 1969; Dodson 1970). The replacement of Daphnia by Bosmina during the cultural eutrophication of Frain's Lake, Michigan has been attributed to increased size-selective predation by fish (Kerfoot, 1974). Deevey (1969) suggested that size selective predation by Chaoborus on the larger sized B. coregoni was responsible for the replacement of B. coregoni by B. longirostris at Rogers Lake, Connecticut.

Crisman (1976) argued against size-selective predation as a cause for the Bosmina species replacement at North Pond, Massachusetts. He

maintained, that the absence of a change in fragmentation rates for Bosmina ruled out predation as an important determinant. However, I believe his reasoning was invalid since if only the type of predators had changed a shift in prey species might be expected without any sign of a change in the amount of predation or fragmentation.

It is unlikely that Chaoborus was responsible for the change in zooplankton composition at Found Lake as the occurrence of Chaoborus remains did not change with either the replacement of B. coregoni by B. longirostris or D. catawba by D. cf. longispina. The influence of changing fish species composition is harder to evaluate as the importance of past planktivore populations are difficult to ascertain. There is a large amount of evidence which demonstrates that the larger herbivores disappear when vertebrate planktivores are introduced to a community (O'Brien et al. 1976; Lynch 1979). Invertebrate predation however has never been shown to be sufficient to completely eliminate the smaller herbivore species (Lynch, 1979).

The pattern unfolded is that size selective predation effectively controls zooplankton community structure (Brooks and Dodson 1965; Dodson 1975). However, under certain circumstances other factors maybe more important than predation. The dominance of small herbivores in vertebrate (fish) free lakes (e.g., Pope and Carter 1975; Nilsson and Pejter 1973; Clark and Carter 1974) indicates that zooplankton species distribution is too complex to be explained solely on the basis of size selective predation. Interspecific competitive abilities vary under different environmental conditions to produce unexpected species distributions. Future theories of community structure will require a better understanding of competition between

species and a knowledge of the relative sensitivity of different species to abiotic factors (Lynch, 1979).

Commencing with a lake's formation zooplankton community dynamics are controlled by invasion rates of new species. Early, during Found Lake's ontogeny, species diversity (Shannon-Weinner) and equitability were low but quickly increased at the start of zone 2 (Fig. 16). The early development of the Found Lake cladoceran community did not follow the pattern of a gradual arrival of new species as has been suggested for several lakes (e.g., Berry Pond and North Pond; Crisman and Whitehead, 1978). Instead species' numbers remained low throughout zone 1 until the start of zone 2a at which time there was a sudden four fold increase (Fig. 16). This rather large increase in species richness took place over a relatively short period of time (245-240 cm). Crisman and Whitehead (1978) speculated that the early development of a cladoceran community is the result of a gradual invasion by new species. The quickness of the phenomenon in Found Lake may suggest that the species were already present but in very low numbers. Amelioration of the climate during zone 2a may have provided the necessary conditions for the development of existing populations.

Alternatively invasion rates may have increased dramatically at this time but it is difficult to speculate why this might have happened.

The increase in species diversity and equitability during zone 2a was associated with an expansion in both the number (Fig. 16) and relative percentage (Fig. 17) of littoral species. The subsequent decline in the latter half of zone 2a was accompanied by an increase in the planktonic cladocera but no decrease in the number of littoral

species. I speculate that climatic amelioration at the beginning of zone 2a may have provided improved conditions for the growth of rooted macrophytes. Littoral zone cladoceran abundance then would have increased until the littoral habitat was saturated. Once aquatic macrophytes had fully occupied the narrow fringe of the littoral zone, any increase in productivity should have stimulated a disproportionate increase in planktonic forms since the littoral species were now presumably limited for space.

This theory is highly speculative and would be difficult to prove without evidence from aquatic macrofossils to demonstrate exactly when macrophyte development had taken place in the lake. The diatom composition (Smol, 1979) suggests that high percentages of littoral species existed well before zone 2a but most are either bottom dwellers or utilize both plant and bottom substrates. However, species considered to be exclusively bottom dwellers were largely replaced by epiphytic or eurytophic species. Furthermore, pollen analysis indicated that spores from aquatic plants, Typha mainly, were consistently higher during pollen zone 2a (Fig. 2). This possibility indicates that macrophyte growth had reached a maximum during this period. The latter decline (zone 2b) of pollen from aquatic plants does not indicate a decline in macrophyte abundance but instead resulted from dilution as pollen influx increased.

It has been proposed that there exists a relationship between a lake's trophic level and the structure of its biotic communities (Cairns et al., 1972). Theoretical considerations suggest that species diversity and equitability should be low in systems with higher levels of production (e.g., Margalef 1969; Slobodkin and Sanders 1969). Whiteside

and Harmsworth (1967) demonstrated an inverse relationship between chydorid species diversity and lake productivity in 33 Danish and Indiana lakes. There is some evidence from the Found Lake core to suggest that lower levels of species diversity and equitability were associated with periods of increased productivity. Following pollen zone 2a, peaks in sedimentary pigments appeared to correlate well with periods of low species diversity. In zone 2a however a positive association was noted between indices of species diversity and productivity. I believe that climatic amelioration during zone 2a provided the conditions necessary for the rare species to expand their numbers (higher diversity) while at the same time increased nutrient availability stimulated a higher level of productivity.

Cladoceran community response to increased primary productivity has not been predictable. The type of structural adjustments communities have undergone has depended on their particular circumstances. In North Pond and Berry Pond, Crisman and Whitehead (1978) observed that periods of increased lacustrine productivity were associated with maximal representation of the planktonic assemblage and minimal representation of the littoral assemblage. During periods of reduced productivity the situation was reversed. The shift to a predominantly planktonic cladoceran fauna was attributed to a reduction of littoral habitat resulting from a decline in the depth of the photic zone due to algal shading. At Found Lake increased primary production was characterized by an increase in both communities (Fig. 11) and very little change in the relative percentage of each community with time (Fig. 15). The algal productivity of Found Lake however has never been high enough to cause shading effects that could limit macrophyte growth.

Thus the littoral Cladocera were able to utilize the increased food availability associated with periods of high primary production without having their habitat restricted by reduced light conditions.

Logic dictates that because of direct nutrient links, secondary productivity should increase along with autotrophic production. Frey (1960) demonstrated a correlation between cladoceran abundance and algal standing crop for several lakes of the Yahara River system in Wisconsin. However, in a more thorough investigation of 33 Danish and Indiana lakes Harmsworth and Whiteside (1968) found no correlation between the numerical abundance of cladocera in surface sediments and lake productivity as measured by radiocarbon techniques.

At Found Lake, cladoceran communities appeared to respond positively to increased primary productivity. However, the cladoceran accumulation rate curve did not usually peak at the same levels as indices of primary production (i.e., sedimentary pigments). There may have been several reasons for this. Variations in algal composition may have accounted for periods of low correlation as not all taxa are equally utilized as a food supply. Furthermore, since the cladocera as a group often comprise only a small proportion of the total zooplankton community of a lake, the validity of estimates based on their abundance are doubtful. Increased secondary production may have involved expansion of an alternate group such as the rotifers or copepods. Even so the high degree of correlation noted for cladoceran microfossils and sedimentary photosynthetic pigments (Figs. 17 and 18) suggests that increased primary productivity generally resulted in increased cladoceran abundance.

Figure 17. Plot of planktonic, littoral, and total cladoceran microfossil concentrations versus concentrations of chlorophyll degradation products for each core level analyzed.

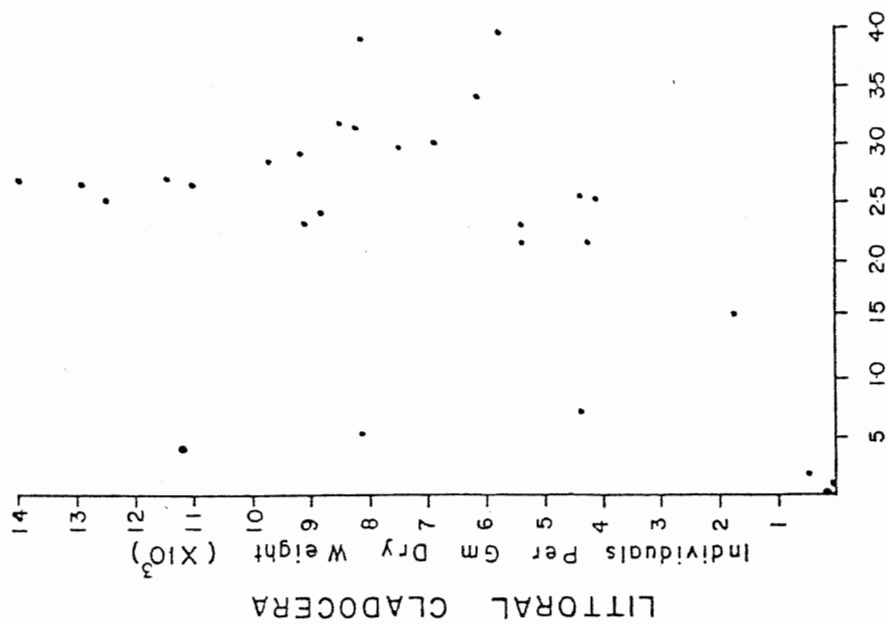
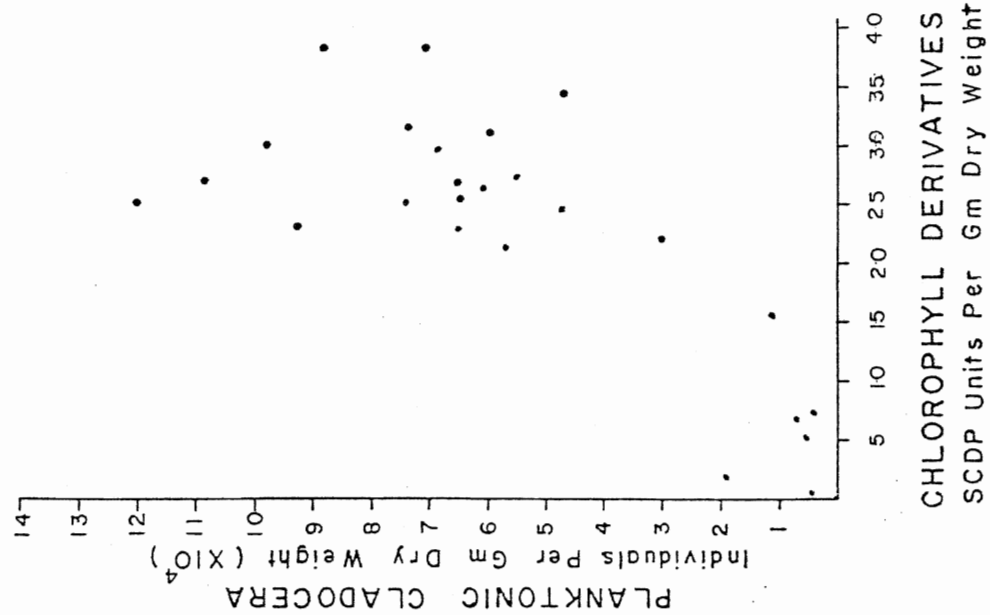
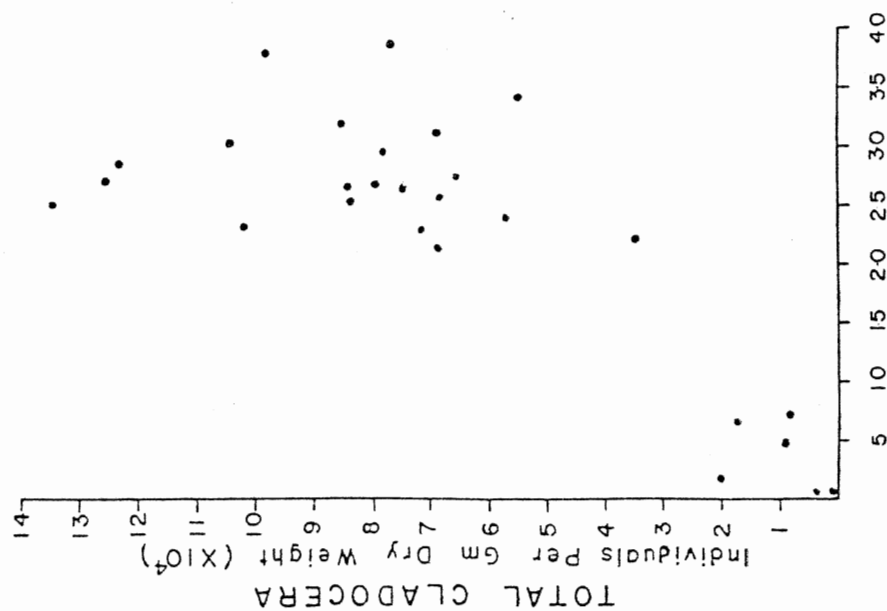
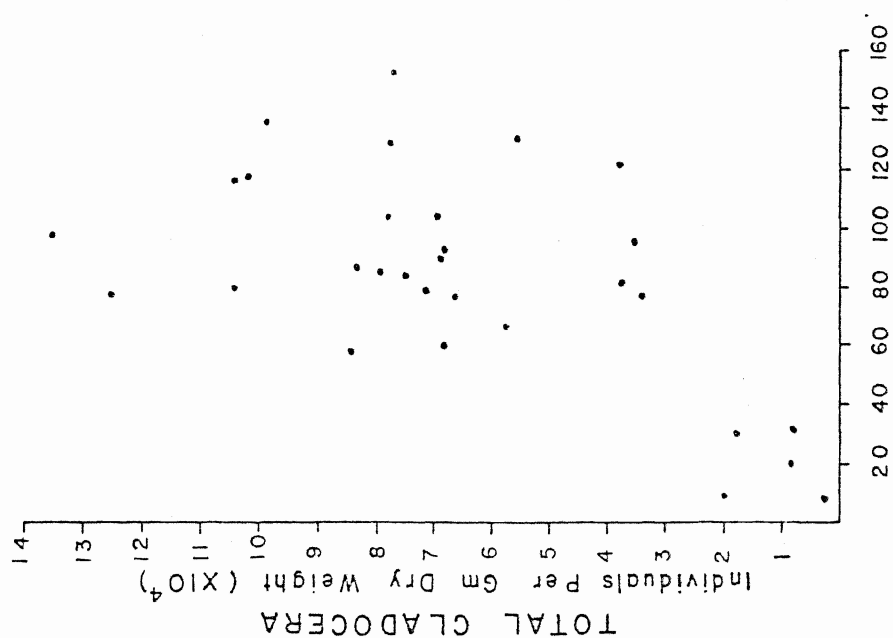
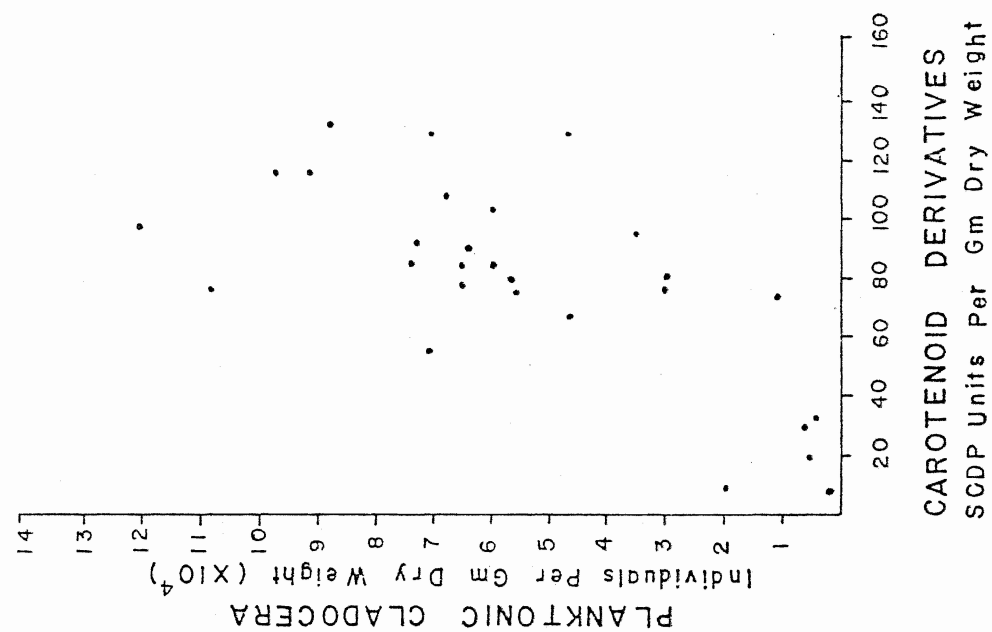
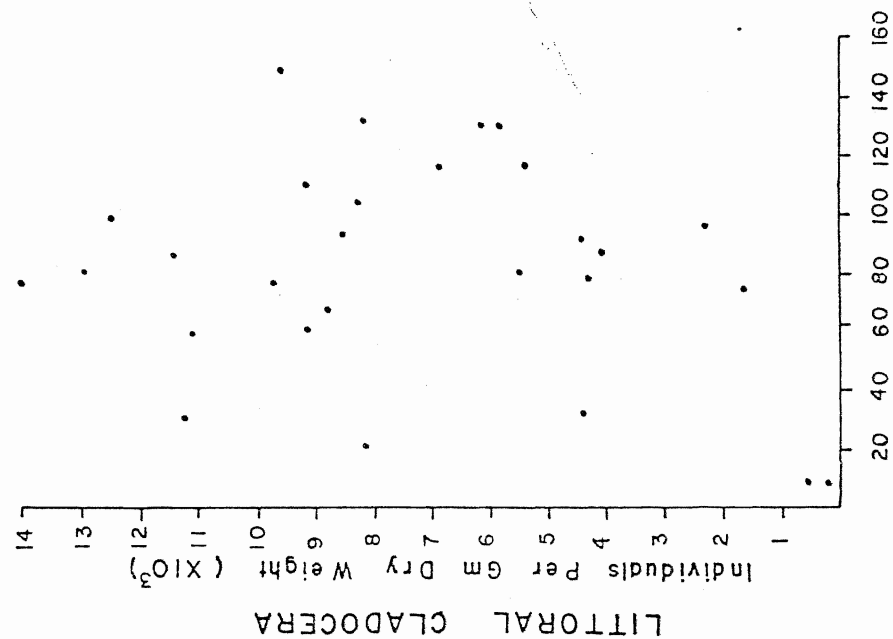


Figure 18. Plot of planktonic, littoral, and total cladoceran microfossil concentrations versus concentrations of carotenoid degradation products.



CAROTENOID DERIVATIVES
SCDP Units Per Gm Dry Weight

Problems Associated With Pollen Analysis

Variations in fossil pollen representation result from differences in pollen production and dispersal mechanisms. Failure to recognize the extent of a species' contribution to the pollen "rain" may lead to a serious misinterpretation of its abundance in past environments. For example in the Found Lake region, some of the most dominant forest components such as hemlock, maple, and spruce, were highly underrepresented in the sedimentary record while others such as pine and oak were overrepresented.

The relationship between pollen "rain" and vegetation must be determined for each vegetational region studied as such relationships change dramatically from one location to another (Livingstone, 1968). Unfortunately, vegetational surveys are not usually available and without them the relative contribution of each species to the pollen "rain" can not be determined. Forest composition data for Algonquin Park made this an ideal area to investigate historical changes in vegetation and the effects such changes have had on watershed-lake interactions.

Pollen and microfossil diagrams were zoned through the combined consideration of two methods. The first consisted of the more "traditional" approach of visual evaluation of species composition. The second quantified the change or dissimilarity between adjacent communities by sequential correlations (Yarranton and Ritchie, 1972). The method consisted of computing the coefficients of correlation for samples from adjacent depths of a sedimentary profile and plotting the coefficients against depth. Core levels displaying a rapid decline in coefficients were designated as boundaries between zones of similar

community types.

Since the establishment of pollen zone boundaries was based on quantitative changes between adjacent core levels it was first necessary to determine the actual contribution of each species to the vegetation i.e., the R value for each taxa.

Product-moment and Spearman's ranked correlation coefficients were chosen as indices of community similarity. The Spearman ranked method was considered inferior since it attached too much importance to rare species. An attempt was made to weight the equation to favour the more abundant taxa but this proved impractical and unnecessary since there was a good correspondance between these results and those generated from the product-moment equation.

The problems inherent in using doefficients of correlation on percentage data were discussed by Yarranton and Ritchie (1972). They concluded that, as a mathematical index of similarity (not a probabilistic measure) between assemblages, the use of correlation coefficients is justified.

Sedimentation and Time Sequence Considerations

Rates of late-glacial and postglacial sedimentation in Found Lake were primarily calculated by using radiocarbon dates. The technique however has a number of problems which can lead to inaccurate determinations of past sedimentation rates. Contamination with older carbon has been of major concern in areas of carbonaceous deposits. In such regions corrections for ^{14}C deficiency must be performed.

Radiocarbon age determinations have another drawback in that they

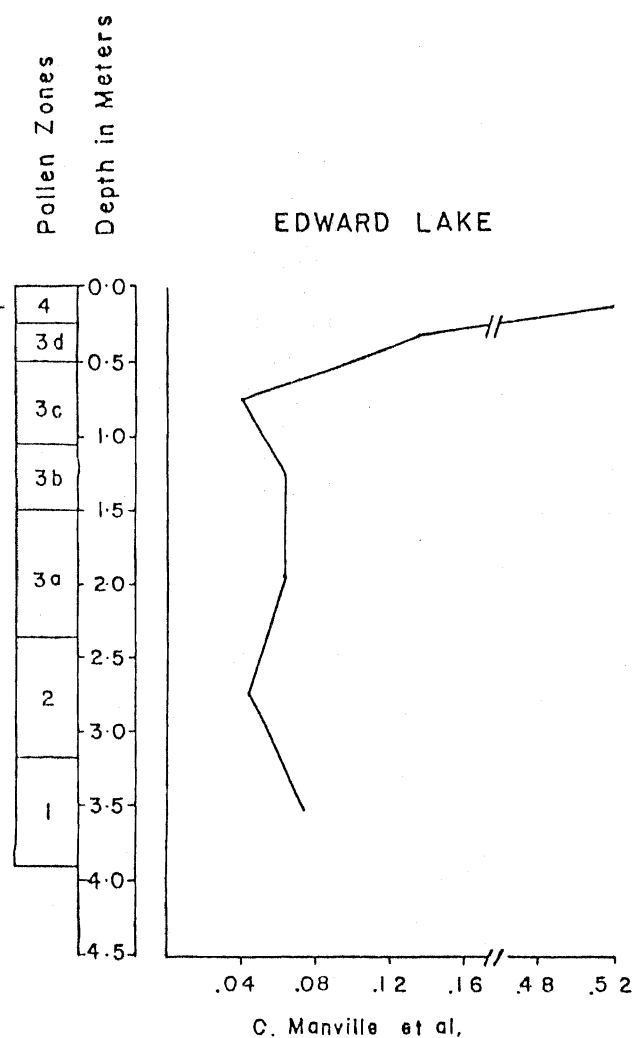
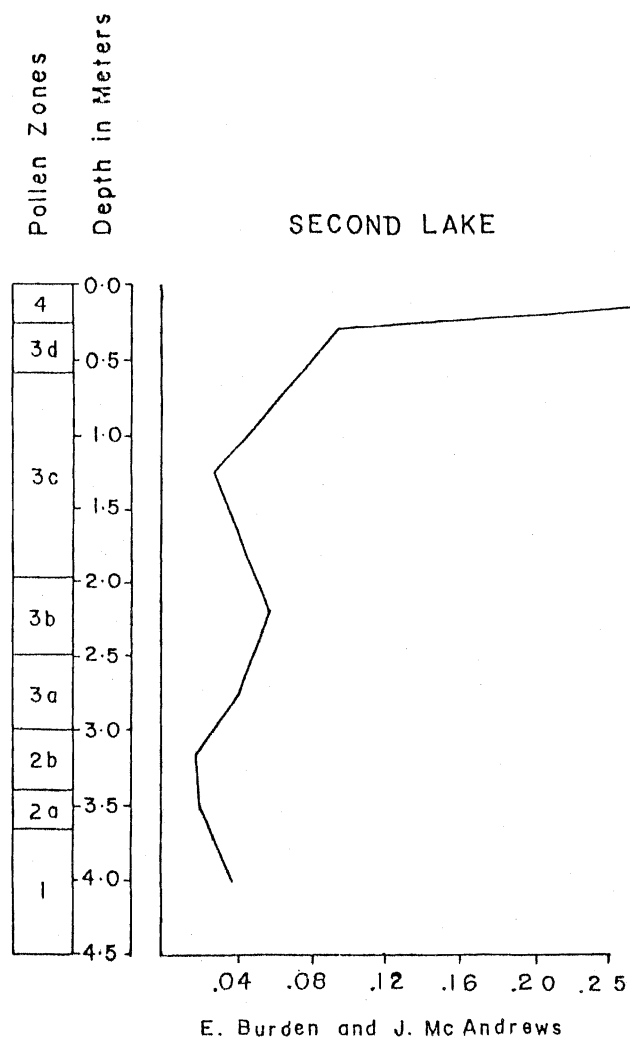
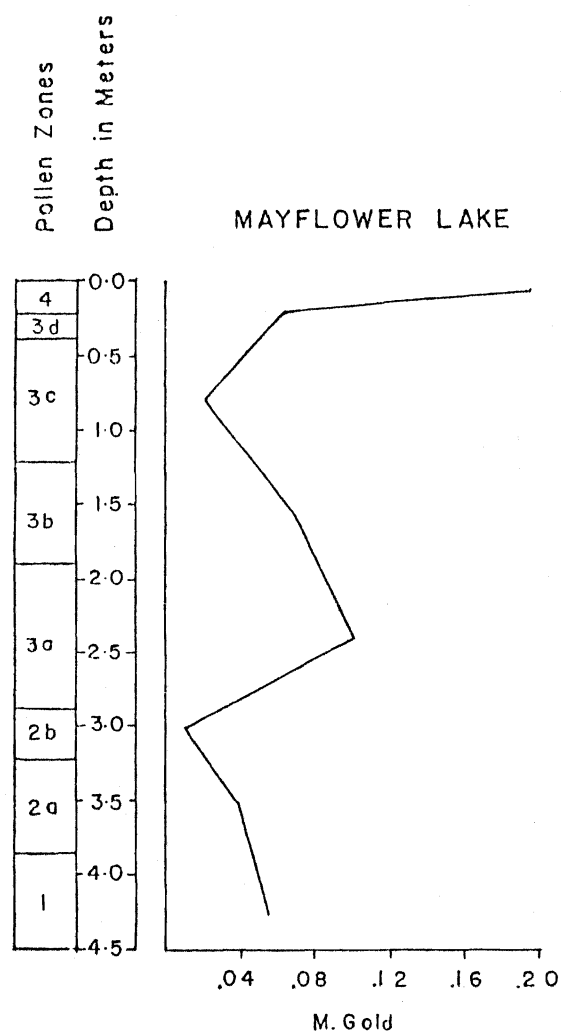
are known to depart from calendar ages because of variations in atmospheric $C^{14}O_2$ (Ralph et al., 1973).

However, the magnitude of the deviations with time have been established and are now being used to provide a correction factor. Since the Found Lake region has no carbonaceous deposits to introduce foreign carbon into the system and C^{14} age determinations have been corrected for any departure from true calendar ages the author feels that the sedimentation rates estimated for the lake are reasonably accurate. Furthermore, the general pattern of the Found Lake sedimentation curve (Fig. 4) resembles those calculated for a number of lakes situated in the Algonquin region (Fig. 19). Sedimentation rates for these lakes have been based on the C^{14} and pollen chronologies of a number of unpublished pollen diagrams.

Variations in sediment matrix accumulation rates can greatly influence any paleoecological interpretation based on the analysis of sedimentary components. It is imperative that biological and chemical parameters be adjusted for any changes in sediment influx rates which might have occurred during a lake's ontogeny. The hypothetical example in figure 20 demonstrates how a change in sediment influx can lead to a misinterpretation of the size of past communities. The concentration of cladoceran remains in sample 1 appeared to be twice as large as in sample 2. Determination of influx rates for each sample however indicates that sample 2 was deposited in half the time. Therefore no change had occurred in the actual size of the communities over time.

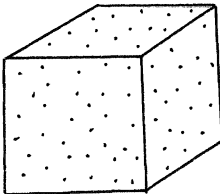
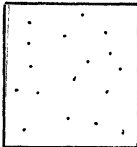
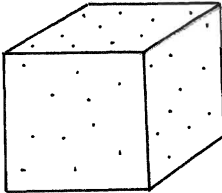
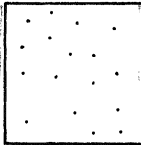
Sedimentation rates, in order to be accurate must be based on a sound chronology. As a general rule, longer cores require more dated core levels than shorter cores. It is indeed fortunate that eight

Figure 19. Sedimentation rate curves for cores from three south central Ontario Lakes; Mayflower Lake, Second Lake, and Edward Lake. Sedimentation rate curves were based on core levels dated by C^{14} and regional pollen chronology. The pollen diagrams are from several unpublished reports. The authors are indicated below each profile.



SEDIMENTATION RATE
(Cm Yr⁻¹)

Figure 20. Hypthetical example demonstrating the influence of sediment matrix accumulation on Cladoceran accumulation rates.

	VOLUME	CLADOCERAN CONCENTRATION	SEDIMENT MATRIX ACCUMULATION RATE	ANNUAL CLADOCERAN ACCUMULATION
Sample 1		200 individuals per cm^2	\div 10 years represented by 1 cm thickness	= 20 individuals deposited on 1 cm^2 each year
				
Sample 2		100 individuals per cm^2	\div 5 years represented by 1 cm thickness	= 20 individuals deposited on 1 cm^2 each year
				

different levels for the 2.85 metre long Found Lake core have been dated. This should provide a reasonably detailed and accurate record of the changes in sediment influx to the lake. Unfortunately, detailed changes between adjacent levels are lost when C^{14} determined sedimentation rates are applied to calculate fossil accumulation rates. Therefore in the absence of a continuous chronology, such as varved sediments provide, the analyst should consider changes in concentrations from one core level to the next as well as changes in accumulation rates. In analysing the Found Lake core it was particularly important to evaluate changes in concentrations near major transitions in paleovegetation zones. Changes in sedimentary parameters at these levels were often larger than the accumulation rate curves indicated.

The central depression of Found Lake from which the core was obtained has probably always been hyperbaloid-like in shape. This suggests that historically, core measured sedimentation rates have not been proportional to the actual influx of sediment to the basin. Models of sediment influx to lakes with hyperbolic basins (Lehman, 1975) have indicated that the rate of accumulation of sediment measured from a core decreases as the basin is filled. For Found Lake this implies that sediment accumulation rates were artificially reduced as sediment depth increased. However, the effect of "sediment focusing" on Found Lake sedimentation rates was probably negligible. In order for these affects to have been appreciable, a much greater sediment depth would have had to accumulate. In steep basined lakes where the total sediment accumulation was high (e.g., Mirror Lake; Likens and Davis, 1975) incorrect interpretations became apparent when core sedimentation rates were corrected for the shape of the basin (Lehman, 1975). This

discussion was stimulated by a concern that peaks in productivity during pollen zones 3b and 4 may actually have been an artificial phenomenon associated with the effects of sediment focusing. But since these events occurred in the later half of the core where measured sedimentation rates were if anything artificially low, productivity measurements for these zones represented a minimum estimate. Although interpretations did not suffer in this study it should become standard procedure in future investigations to consider the influence basin morphology has had on sediment influx rates before interpreting any paleolimnological data.

Relationship Between Vegetation, Nutrients and Aquatic Productivity

Major late-glacial and postglacial oscillations in Found Lake productivity have been documented. The author believes that these oscillations may be related to changes in terrestrial vegetation through its role in regulating nutrient release. Correlation coefficients comparing vegetational changes (1-r pollen) and changes in chemical concentrations and accumulation rates (Table 3) were used to test this hypothesis. They suggest a possible relationship between the amount of change in terrestrial vegetation and the release of phosphorus to the lake. The remaining elements showed no significant correlation with vegetational changes. This suggests the complex nature of nutrient, vegetation and soil interactions. Correlation coefficients based on phosphorus levels and indices used to estimate Found Lake productivity (Tables 4a and 4b) were highly significant

Table 3: Linear correlation coefficients comparing vegetational changes (X_1) and changes in sediment chemical reserves (Y_1) between adjacent core levels.

Vegetational Change (X_1)	Chemical Parameters (Y_1)	Correlation Coefficient (r)	Sample Number (n)
1 - r pollen	% Δ (P)	.358*	13
1 - r pollen	% Δ P _{acc}	.363*	13
1 - r pollen	% Δ (K)	.326	12
1 - r pollen	% Δ K _{acc}	.231	12
1 - r pollen	% Δ (Fe)	.138	21
1 - r pollen	% Δ Fe _{acc}	.084	21
1 - r pollen	% Δ (Mn)	.227	21
1 - r pollen	% Δ Mn _{acc}	.033	21
1 - r pollen	% Δ (Al)	.175	18
1 - r pollen	% Δ Al _{acc}	.1156	18

Explanation of Symbols

K - Potassium acc - accumulation

Mn - Manganese () - concentration

Al- Aluminum % - percentage of previous core level value

P - Phosphorus Δ - change between adjacent core levels

e.g. % Δ (P) reads: percent change in phosphorus concentration

* $p < .05$

Table 4a: Linear correlation coefficients comparing phosphorus concentrations with the concentrations of several sediment core components.

Sediment Component	Phosphorus Concentration	
	"r"	d.f.
Chlorophyll Concentration	.644**	34
Carotenoid Concentration	.595**	34
Cladoceran Concentration	.691**	21
Diatom Concentration	.116	21

Table 4b: Linear correlation coefficients comparing phosphorus accumulation rates with the accumulation rates of several sediment core components.

Sediment Component	Phosphorus Accumulation	
	"r"	d.f.
Chlorophyll Accumulation	.901**	33
Carotenoid Accumulation	.900**	33
Cladoceran Accumulation	.795**	21
Diatom Accumulation	.555*	21

*P < .01

d.f. = degrees of freedom

**P < .001

($P < .001$). The extremely high correlation between phosphorus and sedimentary pigments, although not proof of causality, suggest that phosphorus availability did indeed control past levels of the lake's autotrophic communities.

Correlations between watershed vegetation type, nutrient release, and aquatic productivity were further demonstrated by grouping each sedimentary component according to established pollen zonations. Tables 5 through 7 compare the mean accumulation rates of phosphorus, sedimentary pigments, and cladoceran microfossils for adjacent pollen zones. The results indicated that significant differences in the past levels of productivity and watershed phosphorus release were associated with variations in the composition of the vegetation.

Nutrient Availability and Sediment Chemistry

I propose that the relative availability of phosphorus directly controlled past populations of primary producers within Found Lake. Certain sedimentary indices of aquatic primary productivity such as photosynthetic pigments and algal microfossils responded positively during periods of apparent phosphate enrichment. Presently in Found Lake high nitrogen-to-phosphorus ratios indicate that phosphate is probably the nutrient in shortest supply (Scheider, 1978). Furthermore, phosphate fertilization experiments on several similar lakes in that immediate area demonstrated vast increases in phytoplankton production after fertilization (Langford, 1950).

A great deal of attention in this study has been focused on the watershed as a source of nutrients to the lake while atmospheric inputs

Table 5: Statistical comparison of the mean accumulation rate of sediment phosphorus between adjacent pollen zones. Student-t values indicate the degree of significance between means and F values indicate the amount of between-mean variance.

Pollen Zones Compared	Mean	$F = \frac{S_1^2}{S_2^2}$	Student-t Value	d.f.
1-2a	.183-.051	7.10	5.70***	8
2a-2b	.051-.047	2.40	0.42	10
2b-3a	.047-.62	24.70** ¹	4.16**	9
3a-3b	.162-.272	1.31	2.60*	8
3b-3c	.272-.173	1.96	3.54**	19
3c-3d	.173-.093	15.30** ¹	5.60***	18
3d-4	.093-.462	7.09	5.08**	5

*P < .05

d.f. = degrees of freedom

**P < .01

***P < .001

¹ derived from student-t equation for unequal variance

Table 6a: Statistical comparison of the mean accumulation rate of sedimentary chlorophyll degradation product between adjacent pollen zones. Student-t values indicate the degree of significance between means and F values indicate the amount of between-mean variance.

Pollen Zones Compared	Mean	$F = \frac{S_1^2}{S_2^2}$	Student-t Value	d.f.
1-2a	.018-.025	1.04	0.64	8
2a-2b	.025-.022	7.10	0.31	8
2b-3a	.022-.071	4.20	14.50***	6
3a-3b	.071-.160	3.11	3.63**	11
3b-3c	.160-.099	13.30* ¹	5.30***	24
3c-3d	.099-.193	1378.*** ¹	4.29***	18
3d-4	.193-.523	3.2	3.03*	3

Table 6b: Statistical comparison of the mean accumulation rate of sedimentary carotenoid degradation product between adjacent pollen zones. Student-t values indicate the degree of significance between means and F values indicate the amount of between-mean variance.

Pollen Zones Compared	Means	$F = \frac{S_1^2}{S_2^2}$	Student-t Value	d.f.
1-2a	.187-.120	1.90	1.25	8
2a-2b	.120-.092	3.90	0.43	8
2b-3a	.092-.223	3.88	5.60**	6
3a-3b	.223-.530	44.99*** ¹	3.80**	11
3b-3c	.530-.227	3.49	3.46**	24
3c-3d	.227-.405	25.30*** ¹	3.70**	18
3d-4	.405-1.80	1.29	4.29**	3

*P < .05

d.f. = degrees of freedom

**P < .01

***P < .001

¹ derived from student-t equation for unequal variance

Table 7: Statistical comparison of the mean accumulation rate of cladoceran microfossils between adjacent pollen zones. Student-t values indicate the degree of significance between means and F values indicate the amount of between-mean variance.

Pollen Zones Compared	Mean	$F = \frac{S_1^2}{S_2^2}$	Student-t Value	d.f.
1-2a	28.3-78.0	11.56* ¹	1.02	4
2a-2b	78.0-69.3	1.08	0.13	4
2b-3a	69.3-201.8	9.35	3.05*	5
3a-3b	202-526	3.88	3.74*	8
3b-3c	526-222	1.34	4.90**	12
3c-3d	222-183	5.74	1.12	8
3d-4	183-790	48.0*** ¹	6.40**	2

*P < .05

d.f. = degrees of freedom

**P < .01

***P < .001

¹ derived from student-t equation for unequal variance

have been completely ignored. However, rain water and snow contain chemicals, which in hard rock areas, can form a major source of nutrients to the lake (White et al., 1971). Hutchinson (1957) reported that phosphorus records for rainfall range from a trace to 49 $\mu\text{g/l}$ while Wiebel et al. (1966) found concentrations as high as 80 $\mu\text{g/l}$ in rainfall in a Cincinnati suburb. Duthie (personal communication) proposed that increased precipitation greatly increased the atmospheric input of phosphates to Lake Matamek in Quebec. One might then expect precipitation to be an important source of phosphorus to Found Lake. Unfortunately, even a rough estimate of atmospheric contributions was beyond the scope of this investigation.

I believe what Duthie observed was predominantly a cultural phenomenon. Vapourized and uncontaminated rainwater normally contains relatively few nutrients. Therefore atmospheric contributions to the nutrient budget of Found Lake were probably insignificant during all but the most recent century.

The prevailing redox conditions of past terrestrial and aquatic environments can be interpreted from the ratios of certain chemical elements preserved in the sediments. Under various degrees of anaerobic (reducing) conditions iron and manganese become reduced to the more readily soluble manganous and ferrous forms. When differential reduction occurs in the watershed considerable separation of these elements usually results, since manganese is reduced at higher pH than is iron. The near constancy of the iron-to-manganese ratio throughout the profile indicates that little reductive separation of iron and manganese has occurred in the watershed. With one notable exception, soils have probably never been sufficiently reducing to facilitate the

large scale transport of these elements in dissolved ionic form. Lower Fe-to-Mn ratios during the period of transition from boreal forests to mixed coniferous-deciduous forests may indicate the preferential migration of manganese from the soils of the drainage system. This was probably brought about by a short period of reducing conditions sufficiently intense to produce manganous ion but not intense enough to affect large scale reduction of ferric ion to ferrous ion.

Reduced iron-to-manganese ratios in zone 3d can not be attributed to an increase in the redox condition of the soils. Unlike the low ratio associated with the 185 cm level, iron and manganese did not increase but actually decreased significantly, iron more so than manganese. The decline was probably the result of a change in the influx of plant detritus and organic materials.

Stobbe (1965) has indicated that in well drained podsol soils reducing conditions do not generally exist. Therefore, it is unlikely that large scale mobilization of either iron or manganese has ever occurred in the Found Lake watershed. This supports my conclusions based on the Fe-to-Mn ratios. However, some reductive separation of these elements probably occurred during periods of wet conditions when soils were saturated with water.

Although Fe-to-Mn ratios can be informative their interpretation is not entirely straightforward. Separation of Fe and Mn can take place by alternate mechanisms. For example it has been shown that translocation of iron is brought about by the formation of mobile organo-mineral complexes (Beckwith, 1955; Broadbent and Ott, 1957).

Iron and manganese are not the only elements which can provide an indication of changing redox conditions in past environments. Because

of the solubility properties of Cu and Zn these elements also undergo differential migration in watershed soils (Vuorinen, 1978). Thus Cu-to-Zn ratios can serve as a check for interpretations based on Fe-to-Mn ratios. This is advisable especially since reduction is not the only mechanism which controls the translocation of these elements.

The concentrations of certain rather insoluble elements can provide an indication of the relative importance of sediment erosion throughout a lake's history. In Lake Huleh, Hutchinson and Cowgill (1973) claimed that high concentrations of potassium and aluminum indicate more intense erosion as opposed to leaching of the soil. High concentrations of these elements in the Found Lake core (Fig. 6) were associated with periods of predominate inorganic sedimentation. This was most evident during pollen zone 1 when large quantities of glacial sands and silts were carried into the lake. Interestingly, concentrations in the most recent sediments have increased above the lithosphere averages characteristic of early pollen zone 1. The unusually high Al concentrations characteristic of the last few decades has been attributed to the effects of industrial "acid rain". Acid precipitation has reduced soil pH levels in many regions enough to substantially increase aluminium solubility (Dickson, 1978).

Found Lake's sediment chemistry reflects the lithology of its drainage basin. High concentrations of aluminum, iron, and potassium indicate the predominance of potash feldspars. Extremely high concentrations of Mn, well above the average for igneous rocks (1.0 mg/g Rankama and Sahama 1949), point to a high content of ultrabasics such as biotite, dunite and hornblende. A considerable portion of the sandy sediments contain large quantities of these dark silicate minerals.

Sedimentary iron-to-manganese ratios (4:1) are well below the igneous average (50:1). The presence of granitic pegmatites in the region may explain this unusually low ratio as iron and manganese are about equally represented in pegmatites.

SCDP as an Index of Aquatic Paleoproductivity

Fossil pigments in lake sediments serve as indices to present and past aquatic productivity. Productive lakes with large phytoplankton growths generally exhibit high concentrations of sedimentary pigments while unproductive lakes exhibit low concentrations. However, because of the substantial contributions of allochthonous materials to the sediments it is probably invalid to assume that sedimentary pigments faithfully reflect the past productivity of lakes.

The ratio of chlorophyll derivatives to carotenoids provides an indication of the relative importance of allochthonous vs. autochthonous detritus in sedimentary organic matter (Gorham and Sanger, 1967). In Found Lake the low average pigment ratio (0.3) and the similarity in chlorophyll and carotenoid curves indicates that relatively little allochthonous input has occurred (Sanger and Gorham, 1972). This should be expected considering the lake's relatively small watershed area (0.10 km^2) to surface area (0.13 km^3) and volume ($1.5 \times 10^6 \text{ m}^3$). Furthermore, the mean postglacial chlorophyll concentration (66.8 SCDP units /gm org. wt.) is substantially higher than the average chlorophyll concentrations found for terrestrial forest litter and soil humus layers (< 15 SCDP units/gm org. matter) in the English Lakes District and Minnesota (Gorham and Sanger, 1975).

A preliminary analysis on the separation of sedimentary pigments over starch gel chromatography plates (see Sanger and Gorham, 1970 for methods) indicated that the mean pigment diversity within the Found Lake sediments (34.7 ± 9.2 ; see Table 8) are also considerably higher than those found associated with forest litter (8.8 ± 1.5) and forest humus layers (6.7 ± 0.6). However, the mean pigment diversity number for Found Lake may have been slightly high as no attempt was made to subtract those spots produced by the isomerization of pigment compounds. Nevertheless, isomerization would not have accounted for the differences in diversity found between terrestrial and aquatic materials.

The evidence then suggests that aquatic sources must have contributed substantially to the organic matter of Found Lake's sediments. Therefore, sedimentary pigment levels should reflect the lake's autotrophic production.

Surprisingly the correlation between SCDP accumulation rates and fossil algae was low ($r=.109$ for chlorophyll). Indeed several zones of negative association were evident. The most notable period was during pollen zone 1 when low pigment concentrations and high diatom productivity occurred simultaneously. This example was chosen to demonstrate the uncertainty associated with interpretations based on any one type of evidence. It is particularly dangerous to estimate past levels of primary productivity on the basis of a single group of organisms especially when the group normally comprise only a small proportion of the total autotrophic community. The combined evidence from sedimentary pigments and algal remains not only served to substantiate each other but added information which would not ordinarily have been available

Table 8: Sedimentary pigment diversity for selected levels of the Found Lake core.

<u>Sample Number</u>	<u>Core Level (cm)</u>	<u>Pigment Diversity</u>
1	5.0	30
2	15.5	35
3	15.5	40
4	40.0	42
5	40.0	42
6	75.0	29
7	75.0	27
8	110.0	53
9	110.0	54
10	150.0	40
11	150.0	35
12	180.0	34
13	210.0	24
14	230.0	24
15	230.0	28

Mean Pigment Diversity = 34.7 ± 9.2

through either alone.

The accumulation rates of sedimentary pigments in the recent sediments of pollen zone 4 may be misleadingly high. This would give a false indication of the relative level of primary productivity compared with older periods. Photosynthetic pigments contained within the upper oxidized microzone near the mud-water interface may still be degrading. This being the case pigment concentrations would continue to decrease until sufficient burial had provided an anaerobic environment for their preservation. The extent to which chlorophylls and carotenoids in the upper 4 to 8 cm of sediments would have continued to degrade is rather difficult to determine. Gorham and his colleagues (1974) found that chlorophyll concentrations in Esthwaite sediments decreased nearly 500 percent below the oxidized microzone. However surface chlorophyll concentrations are nearly 4 times higher in the Esthwaite sediments than in Found Lake. Ennerdale Water which has sedimentary chlorophyll concentrations similar to those of Found Lake demonstrated only a 20 percent decrease in chlorophyll concentrations below its oxidized zone. Since the physical-chemical nature and trophic status of Found Lake is not unlike that of Ennerdale Water the concentration of chlorophyll derivatives in its surface sediments probably would not decrease more than about 30 percent before their levels had become stable.

Strong evidence based on the diatom species composition of the uppermost sediments indicates that the top 4 cm of the Found Lake core was missed in coring. The 0 cm level of this core then was most likely below the oxidized boundary when the core was taken. Therefore further degradation of pigment components would not be expected.

The probability that pollen zone 4 (0-10 cm) represents the period of highest primary productivity within Found Lake's history has been suggested by sedimentary chlorophyll and carotenoid data. The trend toward decreased Lake productivity at the 1 cm core level was probably due to the reestablishment of the vegetation after the initial bulldozing of Highway 60 between 1932 and 1934.

The purpose of this study was to investigate watershed-lake interactions and determine those factors which were most important in regulating the biological communities of the lake. Necessarily several sediment core components had to be examined. Among the morphological remains analysed, pollen, algal and cladoceran microfossils were useful indicators of past plant and animal communities. Photosynthetic pigments proved to be helpful in estimating past levels of lacustrine productivity while sediment chemistry was utilized as a means of interpreting the past nutrient resources available for aquatic growth.

The examination of many different lines of evidence has allowed a check on each aspect of the study. It has become clear that no single sediment component can provide an accurate account of past events. Only an interpretation based on several types of evidence can be reliable. More intensive studies combining the efforts of several investigations from a number of scientific fields is needed to solve the remaining paleoecological problems.

CONCLUSIONS

The vegetation of the Found Lake watershed during the past 11,800 years has changed from tundra to coniferous forest and finally to the mixed deciduous-coniferous forest which exists today. These changes in vegetation type have had marked effects on a number of soil parameters. Variations in biomass accumulation rates, soil pH conditions, organic decomposition, and evapotranspiration are believed to have resulted in pronounced stratigraphic changes in watershed chemical release and nutrient mobilization. Differences in the supply of nutrients to the lake during its ontogeny have resulted in substantial oscillations in productivity.

With the exception of the diatoms, aquatic primary productivity was quite low during the period of tundra-open spruce forests (zone 1). This was probably the result of low nutrient availability and high turbidity.

The availability of nutrients in the lake increased as vegetation became more abundant and soils started to develop. Although chemical input to the lake was high, nutrients were largely unavailable for biological utilization as most were contained within glacially eroded rock material. However, sufficient essential nutrients were made available from the poorly developed soils to support abundant populations of diatoms. Atypically low productivity in all algal groups except the diatoms was suspected as accumulation rates of total chlorophycean algae and sedimentary pigments were extremely low during this period. The low abundance of secondary producers found at this time was expected since overall algal productivity appeared to be minimum.

As alder and birch began to replace spruce approximately 10,600 years ago, productivity as estimated from levels of SCDP increased slightly. The presence of alder, through its action as a nitrogen fixer, probably increased soil nitrate levels and reduced soil pH. The availability of phosphate and nitrate in the lake increased as alder, which like those of many other early successional species, contains high levels of both nitrogen and phosphorus and their leaves decompose readily in the aquatic environment. Aquatic productivity was still low however, possibly being limited by competition with terrestrial vegetation for essential nutrients. The forests at this time were relatively open and immature. Early successional forests such as these would utilize all available nutrients and release only small amounts to the lake mainly in the form of organic matter. Molybdenum sequestering by alder although uncommon may have also been important.

Aquatic productivity in all but the chlorophycean algae began to increase with the development of a denser boreal forest at the end of pollen zone 2b. Increased availability of phosphorus and other nutrients were associated with reduced pH conditions in a watershed of dense coniferous forest.

The establishment of a mixed coniferous-deciduous forest at approximately 5,700 Y.B.P. resulted in increased watershed nutrient export. Increased availability of phosphorus associated with increased litter biomass and accelerated rates of decomposition resulted in a higher level of aquatic productivity than was experienced during the boreal forest period.

A peak in aquatic productivity occurred during the marked "hemlock decline" as the result of an increase in watershed chemical release and

nutrient availability. Increased organic decomposition and delivery of allochthonous matter were probably influential in increasing the supply of nutrients to the lake.

The reestablishment of hemlock as an important forest component in pollen zones 3c and 3d reduced the level of Found Lake productivity to about what it had been during pollen zone 3a. Reduced litter biomass, soil pH and organic matter decomposition resulted in a decrease in watershed nutrient release. A postglacial low in watershed nutrient export and phosphorus availability was apparent during zone 3d.

Watershed nutrient release and lacustrine productivity increased greatly during the "disturbed zone", zone 4. The phenomenon did not however appear to be associated with early deforestation by lumbering interests indicating that the lake's watershed may not have been logged. Increased levels of productivity occurred only some decades after the Ambrosia horizon. Watershed nutrient release and aquatic productivity increased as the consequence of activities associated with the construction of highway 60 including forest clearance. Aquatic productivity reached a historical high at this time. This peak has been attributed to algal growth stimulated by materials washed into the lake during the construction of the highway. Watershed nutrient export and phosphorus availability were both high at this time.

The importance of phosphorus as a limiting nutrient to lacustrine productivity is apparent. Found Lake primary productivity closely to variations in sediment phosphorus influx. However, phosphorus availability is not always reflected in the phosphorus accumulation curves. During pollen zone 1, high phosphorus levels coincided with maximal inorganic deposition and extremely low

productivity. Phosphorus-to-cation ratios for Fe, Mn, and Al suggested that large quantities of phosphorus were bound within eroded rock material and as such were largely unavailable for autotrophic growth. Therefore, interpretations of past levels of nutrient availability based solely on stratigraphic changes in sediment chemistry are of questionable value unless supplemented by additional evidence.

Although most cladoceran species are poor indicators of a lake's trophic status, the relative importance of several taxa in biostratigraphic assemblages can be quite informative. The early replacement of Bosmina coregoni by Daphnia catawba and D. catawba by Bosmina longirostris reflect periods of increased lacustrine productivity. These changes were associated with the transition from relatively open forest conditions to dense pine forest and finally to a mixed vegetation. The distribution of Pediastrum araneosum var. rugulosa, considered a highly eutrophic taxa, was restricted to pollen zone 3b. This supports the suggestion that the "hemlock minimum" was a period of mild enrichment and increased productivity.

In conclusion it was found that several distinct types of vegetation have existed around Found Lake since it was first formed. Vegetational changes were correlated with the availability of nutrients during the lake's ontogeny. Nutrient availability appeared to be regulated by a complex interaction of factors relating to vegetation type, soil and water conditions, climate, and erosion.

Indices of lacustrine primary productivity correlated well for the

most part with periods of apparent nutrient availability, especially with phosphorus. Estimates of primary and secondary productivity indicated that two periods of high production occurred within Found Lake. The first was during the "hemlock minimum", zone 3b, when the forests were most deciduous in character. The second was when man modified the land surrounding the lake in conjunction with the construction of highway #60 and caused the once stable soil components to be quickly eroded.

SUMMARY

Pollen analysis of the Found Lake core indicated that the regional vegetation changed from a tundra to a coniferous forest and finally to a mixed coniferous-deciduous forest. Vegetational changes reflected in the pollen analysis suggested that climatic conditions were initially cold and moist during the tundra-open spruce parkland period. The climate became increasingly warmer and drier as the late-glacial vegetation developed into a dense conifer forest. During the postglacial period an increase in the importance of mesophytic species such as maple, beech, and hemlock indicated a trend toward increasing warmth and moisture. The decline in hemlock and its partial replacement by white pine roughly 4,700 years ago reflected a period of warm relatively dry conditions. The reestablishment of hemlock some 800 years later signified the return to moister summers.

The chemical composition of the sediment core provided information about changes in watershed chemistry and nutrient availability. Phosphorus accumulation rates and phosphorus-to-cation ratios correlated well with climatic and vegetational events. Essential nutrients such as phosphorus were most abundant during the postglacial when deciduous trees predominated in the watershed around the lake. Availability appeared to be upmost during the "hemlock minimum". Chlorophyll and carotenoid degradation products (SCDP) suggested that high aquatic primary productivity occurred twice. Once during the "hemlock minimum" and secondly during the recent period referred to as the "disturbed zone". Furthermore, curves for diatom and chlorophycean algal abundance demonstrated large peaks in production during these two periods. Pigment

accumulation rate curves and to a lesser extent fossil algae abundances were correlated with vegetation type and indices of phosphorus availability.

Accumulation rates of fossil cladoceran remains provided information concerning changes in aquatic secondary productivity during the lake's ontogeny. Secondary productivity apparently increased as the coniferous forests reached their densest development roughly 6,200 Y.B.P. A further increase occurred as a mixed forest replaced the coniferous community. Maximum abundances of secondary producers occurred during the "hemlock mimum" and during the "disturbed" zone.

The distribution of several algal and cladoceran "indicator" taxa supported the evidence for these oscillations in the lake's productivity. A compositional change from species characteristic of oligotrophic waters, Bosmina coregoni and Daphnia catawba, to those characteristic of more productive lakes, B. longirostris and D. longispina, occurred when a mixed forest started to develop. Pediastrum araneosum var. rugulosa, considered a highly eutrophic species, was restricted to the "hemlock minimum" where independent evidence suggested that the lake was within one of its most productive phases.

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APPENDIX I

Recipe for Hoyer's Solution

25 ml cornsyrup

5 ml glycerin

15 ml water

mixed gently

Recipes for Chemical Standard Solutions

Standard Phosphorus Solution: 50 ppm (Jackson, 1958): Potassium dihydrogen phosphate (KH_2PO_4) recrystallized at pH 4.5 was dried at 40°C and 0.2195 g dissolved in about 400 ml of distilled water. Then 25 ml of 7N H_2SO_4 was added and the solution diluted to 1 litre.

Standard Iron Solution: 100 ppm (Jackson, 1958); The iron standard was prepared by dissolving 0.7022 g of iron ammonium sulphate ($\text{Fe}(\text{NH}_4)_2 \cdot 6\text{H}_2\text{O}$) in 100 ml of 3.6N H_2SO_4 and diluting to 1000 ml in a volumetric flask.

Recipe for Vanado-molybdate Reagent

Solution A was prepared by dissolving 25 g of ammonium molybdate in 400 ml of warm water (50°C). Then solution B was prepared by dissolving 1.25 g of ammonium metavanadate in 300 ml of boiling water. Solution B was cooled and then 250 ml of concentrated HNO_3 was added and the solution was cooled again to room temperature. Finally solution A was poured into solution B and the mixture was diluted to 1 litre.

APPENDIX II

Preparation of Lacustrine Sediments for Microfossil Analysis

Pollen Preparation Method (modified from Erdtman, 1943)

Step #1 Potassium Hydroxide Treatment: The treatment helps to release the pollen by deflocculating the organic matrix and dispersing the humic acids.

- a) add approximately 12 ml of 10% KOH to the sample in a 15 ml polypropylene centrifuge tube.
- b) heat the sample in a hot water bath at 90°C for 15 minutes; stirring occasionally.
- c) centrifuge for 2 minutes at approximately 7000 rpm and decant KOH by tipping the tube upside down and draining.
- d) wash with distilled water, centrifuge, and decant water.

Step #2 Hydrochloric Acid Treatment: Removes carbonates.

- a) add approximately 8 ml of 10% HCl solution to the sample prepared in step one.
- b) heat in hot water bath (70°C) for 5 minutes.
- c) centrifuge, decant HCl
- d) wash with distilled water, centrifuge and decant water.

Step #3 Hydrofluoric Acid Treatment: The hydrofluoric acid removes silica and the subsequent 10% hydrochloric acid when heated gently removes any colloidal silica and silicofluorides which may precipitate in the water. The glacial acetic acid acts to dehydrate the sample prior to acetolysis

treatment. Acetolysis mixture and water react violently.

- a) add approximately 10 ml of 50% HF to the sample prepared in step 2.
- b) heat in a hot water bath (90°C) for 20 minutes while stirring occasionally.
- c) centrifuge and carefully decant the HF.
- d) add distilled water, centrifuge and decant the dilute HF.
- e) add 5 ml of 10% HCl.
- f) heat gently in a warm water bath (50°C) for 2 minutes.
- g) centrifuge and decant acid.
- h) wash with distilled water, centrifuge and decant water.
- i) add 3 ml of glacial acetic acid, centrifuge, and decant.

Step #4 Acetolysis Treatment: The concentrated H_2SO_4 brings about the depolymerization of cellulose structures and the acetic anhydride converts the cellulose to cellulose triacetate which is soluble in acetolysis solution.

- a) add 5 ml of acetolysis solution (9 parts cold H_2SO_4 to 1 part acetic anhydride) to the sample.
- b) heat in a boiling water bath for 1.5 minutes.
- c) remove from the water bath, centrifuge and decant.
- d) wash with distilled water, centrifuge and decant.
- e) repeat the washing until the acid is completely removed.

Cladoceran Preparation Method (Modified from Crisman, 1976)

Step #1 Potassium Hydroxide Treatment:

- a) add approximately 12 ml of 10% KOH to the sample in a 15 ml polypropylene

centrifuge tube.

b) heat the tube in a hot water bath (90°C) for 15 minutes while stirring the sediment occasionally.

c) centrifuge at approximately 7000 rpm for 2 minutes and decant.

d) wash once with distilled water, centrifuge and decant water.

Note: In all cases decanting should be performed with a bulb pipet making sure the liquid is drawn up slowly without removing any of the sediment.

Step #2 Hydrochloric Acid:

a) Add approximately 8 ml of 10% HCl to the sample prepared in step 1.

b) heat in a hot water bath (70°C) for 5 minutes while stirring occasionally.

c) centrifuge and decant HCl.

Step #3 Hydrofluoric Acid Treatment:

a) add 10 ml of 50% HF to the sample while still in a polypropylene tube.

b) heat in a hot water bath at 90°C for 20 minutes.

c) centrifuge and carefully decant the HF.

d) add distilled water, centrifuge and decant the dilute HF.

e) add 5 ml of 10% HCl.

f) heat gently in a warm water bath (50°C) for 2 minutes.

g) pour any samples with a high silt content into the filtering bucket and use distilled water to wash the sediments through the $40\ \mu\text{m}$ mesh screen on the side of the bucket.

h) pour the filtrate into polypropylene tubes, centrifuge and decant water.

i) if the samples do not require filtering skip to step (j)

j) wash with distilled water, centrifuge and decant.

Step #4 Dilution:

- a) add 10 ml of tertiary butyl alcohol (TBA) to the sample; agitate, centrifuge, and decant.
- b) add approximately 5 ml of TBA; agitate and pour into a graduated cylinder.
- c) rinse the tube out with small amounts of TBA until all the sediment has been removed; note the volume.
- d) pour the sediment-TBA mixture into a 50 ml flask.
- e) rinse the graduated cylinder with a known amount of TBA and pour it into the flask.

Step #5 Slide Preparation

- a) agitate the sediment - TBA mixture on a magnetic stirrer and extract a controlled volume by means of a pipetman 1000.
- b) deliver the aliquot onto a warm (75-80°C) glass slide containing a drop of silicone oil.
- c) add a cover slip after the TBA has evaporated.
- d) secure the four corners with nail hardener and label the slide.

Note: It is important that the temperature be lower than 80°C to avoid loss of material by bubbling and to add just enough silicon oil as excess oil causes the cladoceran remains to flow outside the confines of the coverslip.

APPENDIX III

Absorbance of acetone extracted sediment at 580 nm for selected levels of the Found Lake core expressed as a percentage of the absorbance at 667 nm.

Level (cm)	Percent Absorbance	Level (cm)	Percent Absorbance
1	35.6	105	39.6
1	35.9	105	35.6
1	36.6	110	46.9
3	20.3	110	46.3
3	17.8	110	36.2
3	19.3	120	46.8
5	41.2	120	38.6
12.5	36.8	125	38.6
12.5	38.4	125	37.1
15.5	42.2	130	35.7
15.5	41.0	130	30.0
25.	39.0	135	41.1
25.	35.9	135	40.0
25.	33.9	135	38.3
30.	37.0	140	40.6
30.	44.0	145	39.8
35.	42.6	145	38.8
35.	21.7	145	37.5
35.	47.9	150	29.7
40.	43.2	150	49.7
40.	46.3	150	48.5
45.	45.1	160	48.9
45.	47.6	160	43.0
50.	38.5	165	41.4
55.	41.1	165	42.9
55.	42.6	165	48.1
55.	39.2	170	40.7
60.	39.8	170	40.7
65.	45.8	175	40.1
65.	40.5	175	42.8
70.	42.3	175	41.1
75.	40.8	180	44.9
75.	37.6	180	39.1
75.	32.5	190	49.8
80.	45.9	190	54.4
80.	39.5	190	51.5
85.	30.0	195	47.4
85.	38.9	195	32.2
85.	30.7	195	51.0
90.	45.9	200	51.2
90.	39.5	200	41.2
95.	40.5	205	43.3
95.	42.3	205	41.9
100	47.7	210	37.0
100	43.2	210	44.2

Level (cm)	Percent Absorbance	Level (cm)	Percent Absorbance
215	47.4	225	50.0
215	41.0	230	43.2
215	49.0	230	49.2
220	50.6	235	43.1
220	55.6	235	43.1
220	54.0	240	58.2
225	47.0	240	52.8

APPENDIX IV

Mathematical Formulae Utilized During Investigation

1. Sample Mean (
- \bar{X}
-)

$$\text{Where } \bar{X} = \frac{\sum_{i=1}^n X_i}{N}$$

2. Sample Standard Deviation (S)

$$\text{Where } S = \frac{\sqrt{\sum X_i^2 - N\bar{X}^2}}{N-1}$$

3. Confidence Interval of Sample Mean Estimate

$$= \bar{X} \pm t_{\alpha} \cdot S/\sqrt{N}$$

4. Equation of Straight Line

$$Y_i = mX_i + b$$

5. Product - Moment Correlation Coefficient (r)

$$\text{Where } r = \frac{\sum X_i Y_i - \frac{(\sum X_i)(\sum Y_i)}{N}}{\sqrt{(\sum X_i^2 - \frac{(\sum X_i)^2}{N})(\sum Y_i^2 - \frac{(\sum Y_i)^2}{N})}}$$

6. Residual Sum of Squares (RSS)

$$\text{Where } RSS = \sum Y_i^2 - b \cdot \sum Y_i \cdot \sum X_i Y_i$$

7. Regression Mean Square
- S_1^2

$$\text{Where } S_1^2 = \frac{(\sum X_i Y_i)^2}{\sum X_i} / 1$$

8. Residual Mean Square
- S_2^2

$$\text{Where } S_2^2 = \frac{RSS}{N-2}$$

- 9.
- $F_{cal} = \frac{S_1^2}{S_2^2}$

(1) To test for $H_0: B = 0$

(2) To test for the equality of two variances

11. Testing Significance of r_s

$$\text{Student's } t = r_s \sqrt{\frac{N-2}{1-r_s^2}} ; df = N-2$$

12. Student-t equation (equal variance)

$$t_s = (\bar{X}_1 - \bar{X}_2) \div \sqrt{\frac{1}{N_1} + \frac{1}{N_2} \frac{(N_1-1) S_1^2 + (N_2-1) S_2^2}{N_1 + N_2 - 2}}$$

$$d.f. = N_1 + N_2 - 2$$

13. Student-t equation (unequal variance)

$$t_s = \bar{X}_1 - \bar{X}_2 - (\mu_1 - \mu_2) \div \sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}$$

14. Meaning of Symbols

X_i, Y_i = variables

\bar{X} = mean

N = number of observations

m = slope of line

b = y - intercept of line

t = critical value of student's t at specified level
significance (one tailed test).

F_{cal} = F calculated

t = number of tied observations at a given rank

d_i = difference between the two ranks

$d.f.$ = degrees of freedom

v_1 = $d.f.$ regression

v_2 = $d.f.$ residual

t_{s_1} = student- t value assuming equal variance

t_s = student- t value assuming unequal variance

S = sample standard deviation

$t_{\alpha, N-1}$ = critical t value for α probability given sample
size N

APPENDIX V

Found Lake Core Radiocarbon Age Determinations (Boyko and McAndrews, Unpublished)

<u>Core Level</u> (cm)	<u>Non-Corrected Age Determinations</u> (Y.B.P.)
186	3825 \pm 145 I-7780
251	4640 \pm 95 I-7787
282	4965 \pm 100 I-7988
319	5760 \pm 100 I-7989
365	7790 \pm 175 I-7781
435	10400 \pm 300 I-7782